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**Field Tests of Industrial Stoker  
Coal-fired Boilers for Emissions Control  
and Efficiency Improvement - Site B**

**KVB, Inc, Minneapolis, MN**

**Prepared for**

**Industrial Environmental Research Lab, Research Triangle Park, NC**

**Feb 79**

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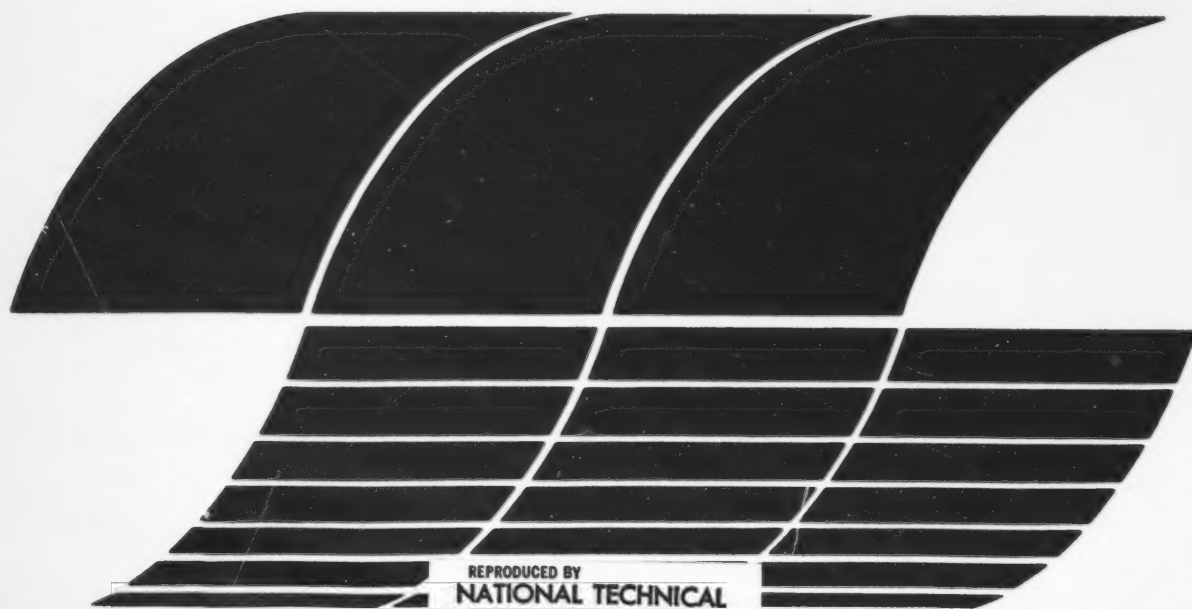
U.S. Environmental Protection Agency  
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Industrial Environmental Research  
Laboratory  
Research Triangle Park NC 27711

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February 1979

# Field Tests of Industrial Stoker Coal-fired Boilers for Emissions Control and Efficiency Improvement-Site B

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| 16. ABSTRACT<br>The report gives results of field measurements made on a 200,000 lb/hr spreader stoker boiler. The effect of various parameters on boiler emissions and efficiency was studied. Parameters studied included overfire air, flyash reinjection, excess air, boiler load, and fuel properties. Measurements included gaseous emissions, particulate emissions, particle size distribution of the flyash, and combustible content of the ash. Gaseous emissions measured were O <sub>2</sub> , CO <sub>2</sub> , CO, NO, SO <sub>2</sub> , and SO <sub>3</sub> in the flue gas. Sample locations included the boiler outlet, multiclone outlet, and electrostatic precipitator outlet. In addition to test results and observations, the report describes the facility tested, coals fired, test equipment, and procedures. Increasing the overfire air flow was found to reduce particulate emissions by 25%. Overfire air flow did not significantly affect NO emissions. A 30% reduction in flyash reinjection reduced particulate loading at the boiler outlet 40%, and reduced boiler efficiency 1.3%. At design capacity, the boiler emitted between 12.7 and 15.8 lb/million Btu particulate matter and 225-315 ppm NO at the boiler outlet. |                 |                                                                      |                               |
| 17. KEY WORDS AND DOCUMENT ANALYSIS                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                 |                                                                      |                               |
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| Air Pollution                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Improvement     | Air Pollution Control                                                | 13B                           |
| Boilers                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Efficiency      | Stationary Sources                                                   | 13A                           |
| Combustion                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Flue Gases      | Combustion Modification                                              | 21B                           |
| Coal                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Fly Ash         | Spreader Stokers                                                     | 21D                           |
| Field Tests                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Particle Size   | Particulate                                                          | 14B                           |
| Dust                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Nitrogen Oxides | Overfire Air                                                         | 11G                           |
| Stokers                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Sulfur Oxides   | Flyash Reinjection                                                   | 07B                           |
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**February 1979**

# **Field Tests of Industrial Stoker Coal-fired Boilers for Emissions Control and Efficiency Improvement - Site B**

by

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**6176 Olson Memorial Highway  
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**IAG/Contract Nos. IAG-D7-E681 (EPA), EF-77-C-01-2609 (DoE)  
Program Element No. EHE624**

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and

**AMERICAN BOILER MANUFACTURERS ASSOCIATION  
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Finally, our gratitude goes to the host boiler facilities who invited us to test their boilers. At their request, these facilities will remain anonymous to protect their own interests. Without their cooperation and assistance this program would not have been possible.

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A Data Supplement Containing all the Data Obtained at Site B is available under the same title (followed by "Data Supplement") and having the same EPA number followed by the letter b rather than a.

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## SECTION 1.0

### INTRODUCTION

In recent years the vast majority of industrial boiler installations have been packaged or shop assembled gas and oil fired boiler units which could be purchased and installed at substantially lower costs than conventional coal burning boiler-stoker equipment. Because of the decline in this market area, little or no work has been done in recent years to improve specification data and information made available to Consulting Engineers and Purchasers of coal burning boiler-stoker equipment. The current implementation of more rigid air pollution regulations has made it difficult for many coal burning installations to comply with required stack emission limits, and this has become a further negative influence on coal burning installations.

A field test program to address this problem has been awarded to the American Boiler Manufacturers Association (ABMA). The program is sponsored by the Department of Energy (DOE) under contract number EF-77-C-01-2609, and co-sponsored by the United States Environmental Protection Agency (EPA), under inter-agency agreement number IAG-D7-E681. The program is directed by an ABMA Stoker Technical Committee which, in turn, has subcontracted the field test portion to KVB, Inc., of Minneapolis, Minnesota.

The objective of the test program is to produce information which will increase manufacturers' ability to design and fabricate stoker boilers which are an economical and environmentally satisfactory alternative to importation and combustion of expensive oil. In order to do this, it is necessary to define stoker boiler designs which will provide efficient operation with minimum gaseous and particulate emissions, and define what those emissions are in order to facilitate preparation of attainable national emission standards for industrial size, coal-fired units.

Further objectives are to: provide assistance to stoker boiler operators in planning for coal supply contracts; refine application of existing pollution control equipment with special emphasis on performance; and contribute to the design of new pollution control equipment.

In order to meet these objectives, it is necessary to determine emissions and efficiency as functions of changes in coal analysis and sizing, degree of flyash reinjection, overfire air admission, ash handling, grate size, etc., for various boiler, furnace and stoker designs.

This report is the Final Technical report for the second of eleven boilers to be tested under the program described above. It contains a description of the facility tested, the coals fired, the test equipment and procedures, and the results and observations of testing. A data supplement to this report contains the "raw" data sheets from the 33 tests conducted. The data supplement has the same EPA report number as this report except that it is followed by "b" rather than "a." As a compilation of all data obtained at this test site, it acts as a research tool for further data reduction and analysis as new areas of interest are uncovered in subsequent testing.

At the completion of this program, a Final Technical Report will combine and correlate the test results from all sites tested. This final report will provide the technical basis for the ABMA publication on "Design and Operating Guidelines for Industrial Stoker Firing," and will be available to interested parties through the ABMA, EPA, or DOE. A separate report covering trace species data will also be written at the completion of this program. It, too, will be available to interested parties through the ABMA, EPA or DOE.

Data in this report is presented in English units. It is EPA policy to use S.I. units in all reports. However, it was determined that English units were necessary in this case. Conversion tables are provided in the appendix for those who prefer S.I. units.

To protect the interests of the host boiler facilities, each test site in this program has been given a letter designation. As the second site tested, this is the Final Technical Report for Test Site B under the program entitled, "A Testing Program to Update Equipment Specifications and Design Criteria for Stoker Fired Boilers."

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## SECTION 2.0

### EXECUTIVE SUMMARY

This section outlines the major relationships and conclusions drawn from the test program at Site B. Comments are organized into groups according to the parameter studied. The test data is summarized in Table 2-1 at the end of this section, and in Tables 5-10 through 5-19 at the end of Chapter 5, Test Results and Observations.

Overfire Air. Increasing the rear overfire air resulted in reduced particulate emissions and increased boiler efficiency. Three overfire air test sets were run with the following results:

- Particulate emissions were reduced 25% at the boiler outlet when the rear overfire air flow was increased by 28%.
- Combustible and inorganic fractions of the particulate emissions were equally reduced by the overfire air in these tests.
- Nitric oxide emissions were not significantly affected by the change in overfire air flow.
- Carbon monoxide emissions were negligible under all conditions tested and, therefore, showed no change.
- Boiler efficiency increased 0.38% in one test set and 2.93% in another test set when overfire air flow at the back of the furnace was increased. The increase in efficiency was attributable for the most part to a reduction in carbon carryover.
- The overfire air system accounts for 20% to 30% of the total air introduced to the furnace at intermediate and high loads.

Flyash Reinjection from the multiclone dust collector was reduced 30% for one high load test. The results were as follows:

- Particulate emissions at the boiler outlet were reduced 39%.

- Particle size distribution data indicate that the largest changes in mass concentration occurred above ten micrometers in size.
- Boiler efficiency was reduced 2.2% by the reduction in re-injection rate. One and one-third percent of this efficiency loss represents the heating value of the 30% flyash not reinjected.

Excess Oxygen and Grate Heat Release. The boiler at Test Site B was tested under a full range of loads and excess air conditions. Some of the relationships observed were as follows:

- Particulate loading was observed to increase with grate air velocity.
- Excess oxygen had only a minor effect on particulate loading and was not an effective control technique for particulate reduction on this boiler.
- Particulate loading at the boiler outlet increased with increasing grate heat release at a rate of about 1.6 lb/10<sup>6</sup>BTU for each 1 x 10<sup>5</sup> BTU/ft<sup>2</sup>-hr. This translates to an 8% increase in particulate loading for each 10% increase in boiler load.
- Nitric oxide concentration increased an average of 30 ppm for each one percent increase in O<sub>2</sub> at constant boiler load.
- Nitric oxide concentration increased an average of 20 ppm for each 10% increase in boiler load at constant excess O<sub>2</sub>.
- Average nitric oxide concentration at the boiler outlet was 270 ppm ± 45 ppm and remained constant at all loads because of the countering effects on NO formation of excess air and boiler load.
- Carbon monoxide emissions were negligible under all conditions tested and, therefore, showed no change.
- Combustible content of the flyash was found to be independent of excess oxygen and only slightly dependent on boiler load. Combustibles were highest in the 70% to 80% load range and dropped off slightly at both ends.
- Boiler efficiency was independent of load, but increased with decreasing excess air at a rate of about 0.6% for each 1% O<sub>2</sub> reduction.

Coal Properties. The four test coals fired in Boiler B were nearly identical in chemical analysis and size consistency. The size consistency of all coals was within the ABMA recommended limits for spreader stokers. The impact of coal selection on emissions and efficiency was as follows:

- Particulate emissions - no relationship observed.
- Nitric oxide emissions - no relationship observed.
- Carbon monoxide emissions - no relationship observed.
- Boiler efficiency - no relationship observed.

Particle Size Distribution of the flyash was measured at the boiler outlet, multiclone outlet, and after the electrostatic precipitator. Bahco classifier, Brink cascade impactor, SASS gravimetric, and sieve methodology were used to measure this parameter. The results are as follows:

- Boiler outlet particulates were measured at 6% below 10 micrometers using the Bahco classifier, and 12% to 39% below 10 micrometers using SASS gravimetrics. The Bahco results were expected to be low because of the method used to obtain the sample. Sieve analysis showed the largest particulate size to be above 1650 micrometers.
- Multiclone outlet particulates were measured at 78% below 10 micrometers using SASS gravimetrics. Extrapolation of the Brink cascade impactor data yielded similar results.
- ESP outlet particulates were measured at 89% and 94% below 10 micrometers using SASS gravimetrics.
- Coal selection, boiler load, and excess oxygen did not show any consistent relationship to particle size distribution of the flyash.

Efficiency of Pollution Control Equipment. Twenty simultaneous particulate loading tests were run across the multiclone dust collector. Two simultaneous particulate tests were run across the multiclone and the electrostatic precipitator combined. The results were as follows:

- Multiclone dust collection efficiency ranged from 92.7% to 96.6% and averaged 94.6%.
- Combined multiclone and ESP efficiency was measured at 99.82% and 99.88%. Thus, ESP efficiency was about 96%

- Combustion variables such as excess air, overfire air, boiler load, and coal selection did not have a discernable effect on collection efficiency.

Modified Smoke Spot Number. Smoke spot readings were taken with a Bacharach smoke spot tester at the boiler outlet using modified procedures. No relationship was found between smoke spot number and either particulate loading or combustible loading.

Source Assessment Sampling System (SASS). Seven SASS tests were run at Test Site B. Five were run at the boiler outlet and two at the ESP outlet. The sample catches are being analyzed for total polynuclear content and seven specific polynuclear aromatic hydrocarbons. Test results will be reported on under separate cover at the conclusion of this test program.

Boiler Emission Profile. Each of the boiler's measured emissions are plotted against grate heat release in this report. In addition, Table 5-19 presents the computed front foot heat release rates and the furnace heat release rates for each test. All of this information will be valuable when comparing the emission profiles of various boiler/stoker combinations and designs. It will also provide accurate data on which to base reasonable emission standards in the future.

The following data table summarizes the reduced data from the tests performed at Test Site B.

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TABLE 2-1. EMISSION DATA SUMMARY, TEST SITE B

| Test No. | Date     | Load % | Coal | Type of Test                             | Conditions            | O <sub>2</sub> % dry | CO <sub>2</sub> % dry | CO ppm dry | NO ppm dry | Part. Blr Out lb/10 <sup>6</sup> BTU | Part. Mech DC Out lb/10 <sup>6</sup> BTU | Excess Air % |
|----------|----------|--------|------|------------------------------------------|-----------------------|----------------------|-----------------------|------------|------------|--------------------------------------|------------------------------------------|--------------|
| 1        | 12/21/77 | 41     | K    | SOx                                      | - as found            | 9.9                  | 9.4                   | 008        | 301        |                                      |                                          | 84           |
| 2        | 12/21/77 | 28     | K    | Part blr out                             | - low load            | 11.3                 | 8.0                   | 008        | 333        | 6.6                                  |                                          | 109          |
| 3        | 1/05/78  | 27     | H    | Part blr & mech out                      | - low load            | 10.9                 | 8.2                   | 245        | 292        | 8.9                                  | 0.54                                     | 100          |
| 4        | 1/06/78  | 47     | K    | Part blr & mech out                      | - as found            | 8.0                  | 11.4                  | 56         | 243        | 9.7                                  | 0.45                                     | 59           |
| 5        | 1/08/78  | 47     | H    | Brink blr out                            | - as found            | 6.6                  | 12.1                  | 45         | 203        |                                      |                                          | 43           |
| 6        | 1/11/78  | 75     | S    | Part blr & mech out                      | - norm OFA            | 5.2                  | 13.7                  | 32         | 214        | 11.7                                 | 0.47                                     | 31           |
| 7        | 1/12/78  | 76     | S    | Part blr & mech out                      | - reduced OFA         | 4.4                  | 14.3                  | 139        | 197        | 10.3                                 | 0.76                                     | 25           |
| 8        | 1/26/78  | 75     | K    | Part blr & mech out                      | - high O <sub>2</sub> | 10.2                 | 8.9                   | 25         | 306        | 15.5                                 | 0.83                                     | 89           |
| 9        | 1/26/78  | 73     | K    | Part blr & mech out                      | - norm O <sub>2</sub> | 6.9                  | 12.1                  | 120        | 237        | 8.2                                  | 0.52                                     | 46           |
| 10A      | 1/27/78  | 31     | S    | Vary excess air                          | - as found            | 11.3                 | 8.4                   | 295        | 351        |                                      |                                          | 110          |
| 10B      |          |        |      |                                          | - reduce              | 10.0                 | 9.0                   | 229        | 311        |                                      |                                          | 85           |
| 10C      |          |        |      |                                          | - reduce              | 8.8                  | 10.1                  | 148        | 273        |                                      |                                          | 68           |
| 10D      |          |        |      |                                          | - increase            | 14.0                 | 5.8                   | 601        | 437        |                                      |                                          | 182          |
| 11       | 1/28/78  | 48     | R    | Part blr & mech out                      | - norm OFA            | 8.8                  | 10.8                  | 96         | 339        | 7.2                                  | 0.48                                     | 69           |
| 12       | 1/28/78  | 49     | R    | Part blr & mech out                      | - reduced OFA         | 8.0                  | 11.8                  | 36         | 280        | 9.6                                  | 0.50                                     | 59           |
| 13A      | 2/03/78  | 72     | R    | Vary excess air                          | - as found            | 7.5                  | 11.6                  | 53         | 267        |                                      |                                          | 53           |
| 13B      |          |        |      |                                          | - reduce              | 5.9                  | 13.0                  | 36         | 226        |                                      |                                          | 37           |
| 13C      |          |        |      |                                          | - reduce              | 4.7                  | 13.9                  | 28         | 194        |                                      |                                          | 27           |
| 14A      | 2/04/78  | 96     | R    | Vary excess air                          | - as found            | 5.8                  | 13.3                  | 24         | 261        |                                      |                                          | 36           |
| 14B      |          |        |      |                                          | - reduce              | 4.6                  | 14.5                  | 22         | 258        |                                      |                                          | 27           |
| 14C      |          |        |      |                                          | - reduce              | 3.4                  | 15.4                  | 125        | 225        |                                      |                                          | 18           |
| 14D      |          |        |      |                                          | - increase            | 6.4                  | 12.8                  | 34         | 296        |                                      |                                          | 42           |
| 15       | 2/06/78  | 87     | R    | Sass, Part, SOx blr & ESP out            | - low O <sub>2</sub>  | 4.3                  | 14.7                  | 27         | 215        | 12.5                                 | 0.023*                                   | 25           |
| 16       | 2/07/78  | 89     | R    | Sass, Part, SOx blr & ESP out            | - norm O <sub>2</sub> | 7.0                  | 12.1                  | 48         | 294        | 14.6                                 | 0.018*                                   | 47           |
| 17       | 2/09/78  | 88     | R    | Part blr & mech out                      | - norm O <sub>2</sub> | 6.6                  | 12.4                  | 47         | 320        | 10.7                                 | 0.47                                     | 44           |
| 18       | 2/17/78  | 74     | S    | Part blr & mech out - pulling bottom ash |                       | 6.5                  | 12.9                  | 163        | 287        | 12.8                                 | 0.81                                     | 43           |
| 19       | 2/18/78  | 75     | K    | Part blr & mech out                      | - low O <sub>2</sub>  | 4.7                  | 14.4                  | 35         | 239        | 10.5                                 | 0.56                                     | 28           |
| 20       | 2/18/78  | 73     | K    | Part blr & mech out                      | - norm O <sub>2</sub> | 6.8                  | 12.4                  | 35         | 332        | 10.8                                 | 0.56                                     | 46           |
| 21       | 2/20/78  | 73     | H    | Part blr & mech out                      | - norm OFA            | 6.8                  | 12.4                  | 34         | 310        | 9.2                                  | 0.62                                     | 46           |
| 22       | 2/20/78  | 72     | H    | Part blr & mech out                      | - reduced OFA         | 6.3                  | 12.9                  | 103        | 219        | 12.3                                 | 0.82                                     | 41           |
| 23       | 2/22/78  | 99     | K    | Part blr & mech out                      | - reduced reinj       | 5.5                  | 13.6                  | 41         | 254        | 9.6                                  | 0.49                                     | 34           |
| 24       | 3/02/78  | 99     | S    | Part & sizing blr & mech out             | - max load            | 5.1                  | 13.9                  | 72         | 256        | 13.9                                 | 3.53                                     | 31           |
| 25       | 3/03/78  | 100    | K    | Part & sizing blr & mech out             | - max load            | 5.3                  | 13.7                  | 60         | 317        | 15.8                                 | 0.60                                     | 32           |
| 26       | 3/05/78  | 99     | H    | Part blr & mech out                      | - max load            | 5.3                  | 13.7                  | 83         | 287        | 12.7                                 | 0.64                                     | 32           |
| 26C      |          |        |      | Sizing blr & mech out                    | - max load            | 4.4                  | 14.7                  | 62         | 252        |                                      |                                          | 25           |
| 27       | 3/09/78  | 79     | K    | Part blr & mech out                      | - reduced OFA         | 6.4                  | 12.6                  | 44         | 311        | 11.7                                 | 0.59                                     | 42           |
| 28       | 3/09/78  | 81     | K    | Part blr & mech out                      | - norm OFA            | 6.5                  | 12.7                  | 47         | 305        | 10.0                                 | 0.34                                     | 43           |
| 29       | 3/16/78  | 79     | K    | Gaseous only                             | - as found            | 6.6                  | 12.5                  | 40         | 259        |                                      |                                          | 44           |
| 30       | 3/17/78  | 78     | H    | SASS blr out, SOx blr & ESP out          | - as found            | 6.0                  | 13.0                  | 46         | 232        |                                      |                                          | 38           |
| 31       | 3/18/78  | 77     | K    | SASS blr out, SOx blr & ESP out          | - as found            | 6.0                  | 13.0                  | 27         | 259        |                                      |                                          | 38           |
| 32       | 3/20/78  | 78     | H    | SOx blr out                              | - as found            | 5.9                  | 13.1                  | 31         | 235        |                                      |                                          | 37           |
| 33       | 3/21/78  | 79     | S    | SASS blr out, SOx blr out                | - as found            | 6.1                  | 12.9                  | 47         | 241        |                                      |                                          | 39           |

NOTES: Gaseous data (O<sub>2</sub>, CO<sub>2</sub>, CO, NO) obtained at boiler outlet  
 Particulate and SOx data obtained at location specified under "Type of Test"  
 Coal Supplier: K-Kentucky Cumberland, H-Hatfield, S-Southeast, R-Reload from long term storage

\* Tests 15 and 16 Particulates measured at the boiler outlet and the ESP outlet

NO<sub>2</sub> data was not acquired due to inserviceability of NOx converter portion of NO-NO<sub>2</sub> analyzer

Conversion tables are given in the appendix for converting from English units to SI units

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## SECTION 3.0

### DESCRIPTION OF FACILITY TESTED AND COALS FIRED

This Section discusses the general physical layout and operational characteristics of Boiler B. The coals utilized in this test series are also discussed.

#### 3.1 BOILER B DESCRIPTION

Boiler B is a single pass Riley boiler with Riley spreader stoker. It has a continuous rating of 200,000 lb/hr steam. Current operation of the boiler is at 185 psi and 500°F steam with 225°F feedwater. However, the boiler was designed for 750 psi to allow for future upgrading to 650 psi at 750°F steam with 350°F feedwater. A sectional side elevation of the unit is shown in Figure 3-1. An abbreviated list of boiler design data follows:

Riley Boiler (VOSP) built 1974

|                                                           |                                             |
|-----------------------------------------------------------|---------------------------------------------|
| Rated Steaming Capacity (continuous)                      | 200,000 lb/hr                               |
| Peak Steaming Capacity (2 hrs in 24)                      | 220,000 lb/hr                               |
| Economizer Heating Surface                                | 4,110 ft <sup>2</sup>                       |
| Superheater Heating Surface                               | 1,900 ft <sup>2</sup>                       |
| Water Wall Heating Surface                                | 2,820 ft <sup>2</sup>                       |
| Boiler Heating Surface                                    | 15,038 ft <sup>2</sup>                      |
| Furnace Width (centerline to centerline water-wall tubes) | 20'7-3/4"                                   |
| Furnace Depth (front to back)                             | 17'4-11/16"                                 |
| Furnace Height (mean)                                     | 36'0"                                       |
| Furnace Volume                                            | 12,910 ft <sup>3</sup>                      |
| Design Pressure                                           | 750 psig                                    |
| Operating Pressure                                        | 185 psig                                    |
| Feedwater Temperature                                     | 255°F                                       |
| Final Steam Temperature (superheater)                     | 500°F                                       |
| Furnace Heat Release                                      | 2.0x10 <sup>4</sup> BTU/ft <sup>3</sup> /hr |
| Furnace Residence Time                                    | 2.7 sec                                     |
| Velocity Flue Gas in Furnace                              | 11.6 ft/sec                                 |
| Velocity Flue Gas Entering Boiler                         | 51 ft/sec                                   |
| Velocity Flue Gas Entering Economizer                     | 52 ft/sec                                   |
| Controls                                                  | Foxboro                                     |
|                                                           | KVB 15900-524                               |

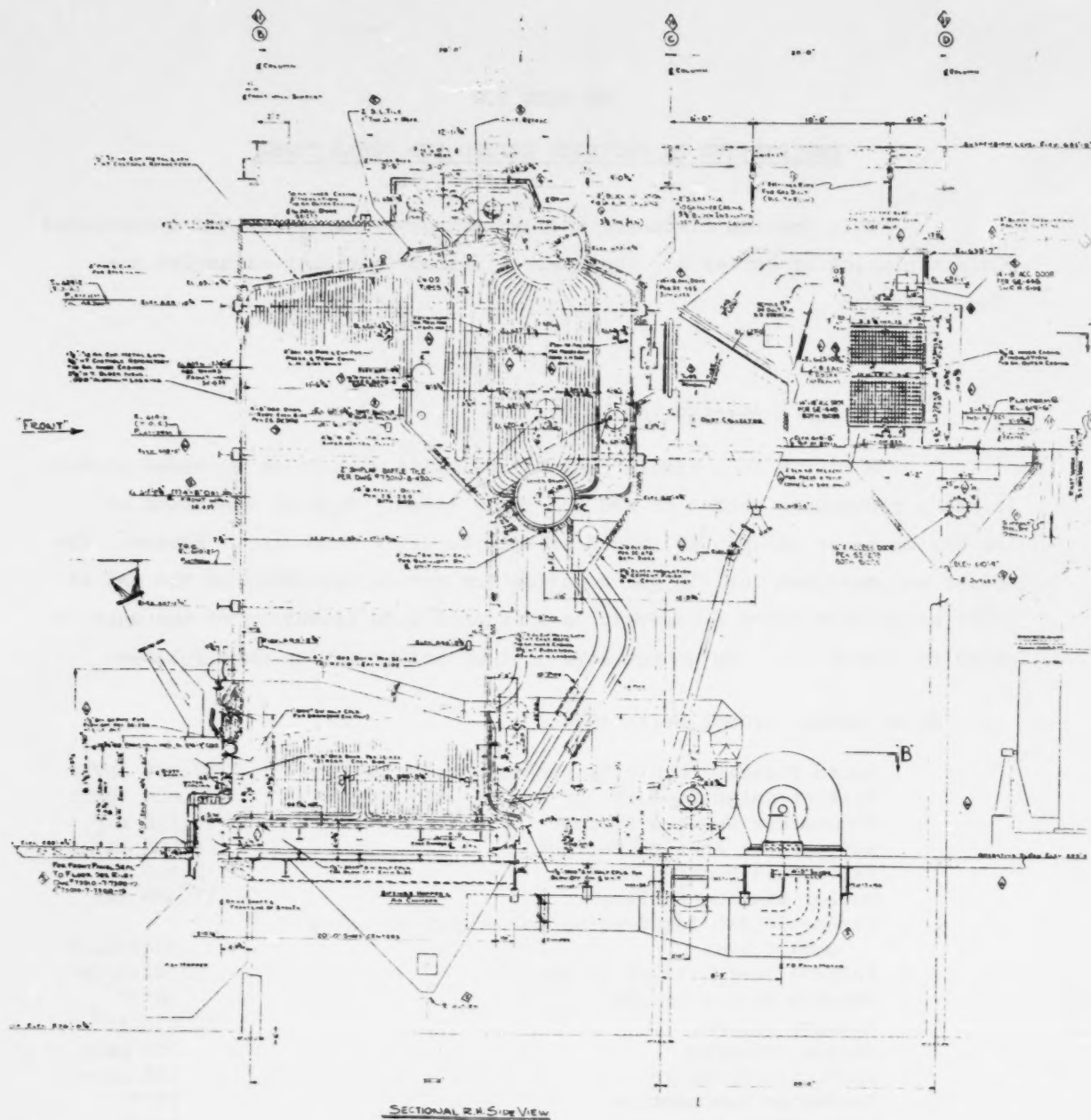


Figure 3-1. Boiler B sectional side elevation

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## Riley Stoker

|                                      |                                             |
|--------------------------------------|---------------------------------------------|
| Feeders                              | 5 - Riley model F                           |
| Grate Type                           | Split traveling grate with front discharge  |
| Grate Width                          | 20'0-3/8"                                   |
| Grate Length (between shaft centers) | 20'0"                                       |
| Effective Grate Area                 | 370 ft <sup>2</sup>                         |
| Grate Heat Release                   | 7.4x10 <sup>5</sup> BTU/ft <sup>2</sup> /hr |

### 3.2 OVERFIRE AIR SYSTEM

The overfire air system on Boiler B consists of two rows of 17 jets each on the back wall and one row of 17 jets on the front wall above the feeders. In addition, the OFA fan supplies air to the air swept cut-off plate and deflector tuyeres for cooling, and to two 3/4 inch underfeeder air jets under each of the five Riley feeders.

The overfire air fan extracts air from the undergrate air duct downstream of the forced draft fan. It was set up by a Riley service man so that most of the air enters the rear of the furnace and very little enters through the front wall. This was intended to create a circulation in the furnace which would sweep up the front wall and down the rear wall. Dampers on the two rear overfire air headers are ganged together and can be operated remotely from the panel board.

The overfire air design data is as follows:

|                |                                                                                                                                       |
|----------------|---------------------------------------------------------------------------------------------------------------------------------------|
| Front Row:     | 17-1-1/4" nozzles<br>spaced @ 13-1/4" (8-9/32" adjacent to center nozzle)<br>7'8-5/8" above grate<br>18° 30' below horizontal         |
| Rear Rows (2): | 17-1-1/4" nozzles each row<br>spaced @ 13-1/4"<br>2-1/2° below horizontal<br>Upper row 5'9" above grate<br>Lower row 2'0" above grate |

|                              |            |                      |
|------------------------------|------------|----------------------|
| As Found Operating Pressures | Front      | 7" H <sub>2</sub> O  |
|                              | Rear Upper | 22" H <sub>2</sub> O |
|                              | Rear Lower | 25" H <sub>2</sub> O |

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Boiler B reinjects flyash continuously from the boiler hopper and from a portion of the centrifugal dust collector. The dust collector is a VOP Design 104 Dynamic Centrifugal Collector having 140 ten-inch collection tubes. It is equipped with front storage hoppers and rear reinjection trough hoppers. According to the proposal specifications, 60 to 80% of the collected flyash is reinjected. Internal dampers are designed to direct the larger particles to the reinjection trough. In theory this is a good idea because the larger particles contain a larger carbon component and are less likely to be re-entrained in the flue gas. The collector has a guaranteed efficiency of 90% based on an inlet dust analyzing ten percent less than ten micrometers.

No provisions were made for diverting the ash from the reinjection system to a storage hopper or alternate disposal system. Thus, in order to stop the reinjection for test purposes, it was necessary to remove the venturi section at the bottom of the hopper spouts and add a section of pipe to extend the downspouts into sealed, air tight, 55 gallon drums. There were no rotary dust valves on the downspouts to compensate for the negative pressure in the hoppers.

Design data on the flyash reinjection system is as follows:

|                               |                                                                                                                     |
|-------------------------------|---------------------------------------------------------------------------------------------------------------------|
| Boiler Hopper:                | 6 - 2-1/2" discharge nozzles<br>spaced @ 2'9-1/8" (center two @ 3'3-3/4")<br>18" above grate<br>7° below horizontal |
| Dust Collector Hopper:        | 7 - 2-1/2" discharge nozzles<br>spaced @ 6'10-13/16"<br>18" above grate<br>7° below horizontal                      |
| As Found Operating Pressures: | Boiler hopper reinjection hdr - 5" H <sub>2</sub> O<br>Mechanical hopper reinjection hdr - 5" H <sub>2</sub> O      |

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## 3.4

## PREDICTED PERFORMANCE DATA

Boiler B predicted performance data is given in Table 3-1 below. The performance predictions are based on a coal which is not less favorable than 1-1/4" nut to slack for friable coal, 3/4" nut to slack for non-friable coal, and with not more than 50% passing through a 1/4-inch round mesh screen. The coal shall be delivered across the feeder hopper without segregation.

TABLE 3-1. BOILER B PREDICTED PERFORMANCE DATA

|                                                             | Without Reinjection<br>from D.C. | Reinjection<br>from D.C. |
|-------------------------------------------------------------|----------------------------------|--------------------------|
| Steam Flow - PPH                                            | 200,000                          | 200,000                  |
| Blowdown - PPH                                              | 10,000                           | 10,000                   |
| Boiler Exit Gas - °F                                        | 584                              | 578                      |
| Economizer Outlet Gas - °F                                  | 350                              | 350                      |
| Coal - PPH                                                  | 20,731                           | 20,170                   |
| Air - PPH                                                   | 270,353                          | 263,037                  |
| Gas - PPH                                                   | 289,011                          | 281,190                  |
| Heat Release - BTU/sq.ft.                                   | 82,682                           | 80,444                   |
| Grate Heat Release - BTU/sq.ft.                             | 695,000                          | 676,000                  |
| Heat Release - BTU/cu.ft.                                   | 19,912                           | 19,373                   |
| * Dust Loading - #/MKB                                      | 1.86                             | 5.57                     |
| * Dust Loading - Grains/ACFM                                | .59                              | 1.77                     |
| Efficiency                                                  | 81.88                            | 84.16                    |
| Excess Air in Flue Gas (%)                                  | 31                               |                          |
| Ambient Air Temperature - °F                                | 80                               |                          |
| Steam Quality - PPM                                         | 1                                |                          |
| Steam Temperature Leaving Boiler - °F                       | 500                              |                          |
| Superheater Outlet Pressure - PSIG                          | 185                              |                          |
| Draft Loss - FD Duct - "W.C.                                | 0.87                             |                          |
| Draft Loss - Stoker Grate - "W.C.                           | 2.18                             |                          |
| Draft Loss - Boiler - "W.C.                                 | 1.33                             |                          |
| Draft Loss - Dust Collector - "W.C.                         | 3.15                             |                          |
| Draft Loss - Economizer - "W.C.                             | 2.72                             |                          |
| Draft Loss - Electrostatic Precipitator and<br>ID Duct Work | 1.75                             |                          |
| Total FD Draft Loss                                         | 3.06                             |                          |
| Total ID Draft Loss - "W.C.                                 | 8.94                             |                          |

\* Based on 20% Ash

|                               |                             |
|-------------------------------|-----------------------------|
| <u>Fuel:</u> Coal - C - 72.3% | N <sub>2</sub> - 1.2%       |
| H <sub>2</sub> - 4.9%         | O <sub>2</sub> - 5.0%       |
| S - 0.6%                      | H <sub>2</sub> O - 6.0%     |
| Ash - 10.0%                   | HHV as fired 12,400 BTU/lb. |

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### 3.5

#### TEST PORT LOCATIONS

Sample ports were installed at the locations shown on the boiler schematic, Figure 3-2. Whenever particulate loading was measured it was measured simultaneously at the boiler outlet and at the mechanical collector outlet using a 24-point traverse. The geometry of these two sample locations is shown in Figure 3-3. On two occasions particulate loading was measured at the electrostatic precipitator outlet. This duct, not illustrated here, had a cross-sectional area of 28.53 ft<sup>2</sup>. It led directly to the stack, and the dust loadings measured at the precipitator outlet should be very close to what would be measured at the stack in a compliance test.

A gaseous probe was placed in the center of the duct through each of the six test ports at the boiler outlet. Gaseous measurements of O<sub>2</sub>, CO<sub>2</sub>, CO and NO were obtained by pulling both individual and composite samples through these probes. When particulates were being sampled, gaseous samples were pulled simultaneously from all ports except the one containing the particulate probe at the boiler outlet. The gaseous concentrations reported are the average of many readings taken over the course of testing.

A heated sample line was attached to one of the middle gaseous probes at the boiler outlet. Its purpose was to eliminate losses due to condensation when measuring NO<sub>2</sub> and unburned hydrocarbons. However, problems due to hydrocarbon contamination of the sample line and electro mechanical problems with both the hydrocarbon analyzer and the NO<sub>x</sub> converter prevented these measurements from being made.

### 3.6

#### COALS UTILIZED

Four coals were test fired on Boiler B during the test program. The chemical properties of these coals are summarized in Table 3-2. All four coals were Eastern bituminous low-sulfur coals. They differed very little from one another. A complete fuel analysis summary for each coal is presented in Tables 5-14 through 5-18 in Section 5.0, Test Results and Observations.

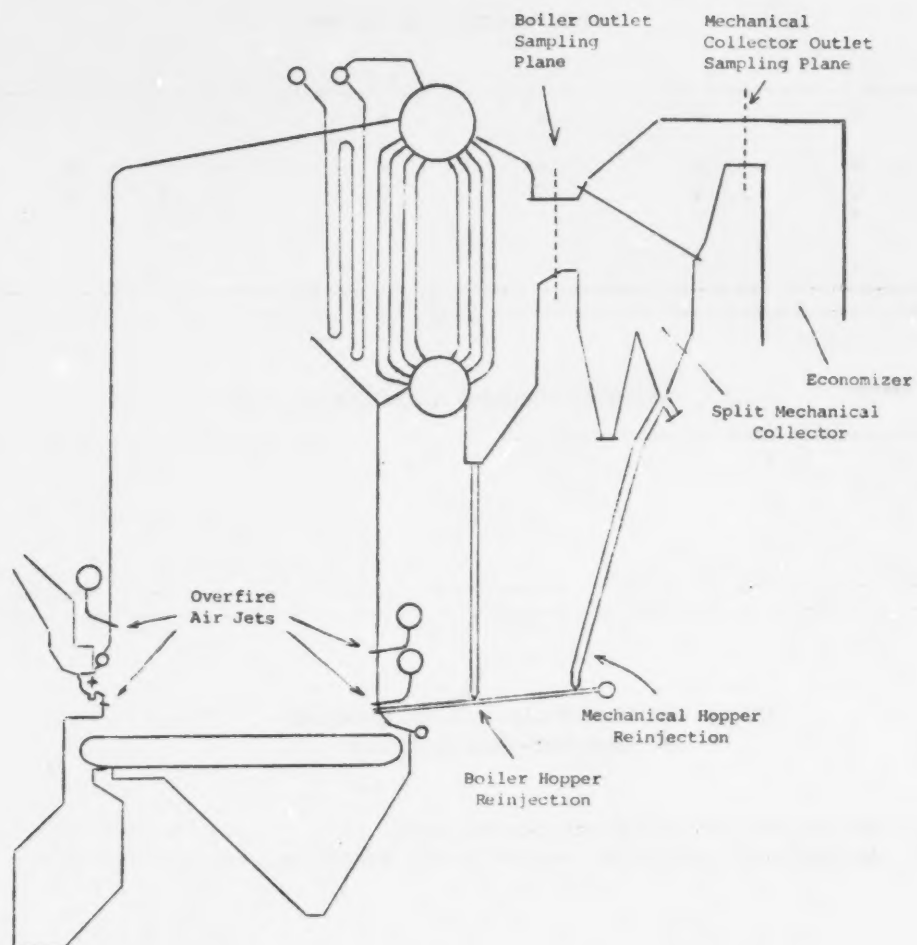
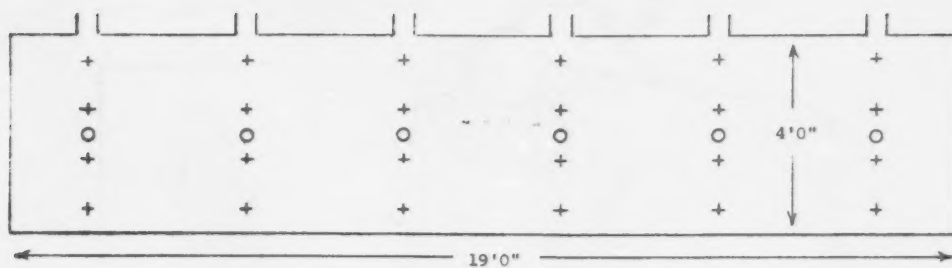


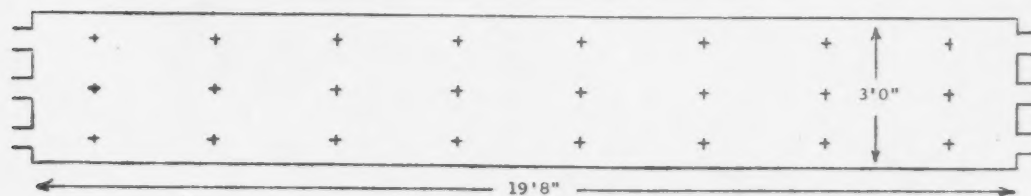
Figure 3-2. Boiler B schematic

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BOILER OUTLET SAMPLING PLANE



MECHANICAL COLLECTOR OUTLET SAMPLING PLANE



KEY: + Particulate sample point  
o Gaseous sample point

Boiler outlet cross sectional area = 76.0 ft<sup>2</sup>  
Mechanical collector outlet cross sectional area = 59.0 ft<sup>2</sup>

Figure 3-3. Boiler B sample plane geometry

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TABLE 3-2. AS-FIRED PROXIMATE ANALYSIS  
OF COALS TESTED IN BOILER B

| Coal Supplier                                | Kentucky<br>Cumberland | Hatfield | Southeast | Reload |
|----------------------------------------------|------------------------|----------|-----------|--------|
| % Moisture                                   | 4.27                   | 3.93     | 2.90      | 4.38   |
| % Ash                                        | 7.72                   | 8.79     | 9.02      | 6.40   |
| % Volatile                                   | 34.24                  | 33.65    | 34.19     | 34.71  |
| % Fixed Carbon                               | 53.77                  | 53.63    | 53.89     | 54.51  |
| BTU/lb                                       | 13220                  | 13137    | 13201     | 13432  |
| % Sulfur                                     | 0.90                   | 0.93     | 0.78      | 0.77   |
| Initial Deformation<br>of Ash (Reducing), °F | 2490                   | 2550     | 2607      | 2700+  |

Coal selection at Test Site B was affected by a coal strike. During tests 1 through 10 and 18 through 33, railway car loads of coal arrived almost daily from three suppliers. This coal was loaded directly into live storage. For this reason, the coal fired changed almost daily and test plans could be made no more than two or three days in advance. During tests 11 through 17 the facility was forced to burn coal from its dead storage some distance from the power plant. This coal, comprised of an unknown blend of many coals, was transported to the site in trucks and unloaded into live storage. It will often be referred to as "Reload" coal in this report.

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## SECTION 4.0

### TEST EQUIPMENT AND PROCEDURES

This section details how specific emissions were measured and the sampling procedures followed to assure that accurate, reliable data were collected.

#### 4.1 GASEOUS EMISSIONS MEASUREMENTS (NO, NO<sub>2</sub>, CO, CO<sub>2</sub>, O<sub>2</sub>, HC)

A description is given below of the analytical instrumentation and related equipment, and the gas sampling and conditioning system, all of which are located in a mobile testing van owned and operated by KVB. The systems have been developed as a result of testing since 1970, and are operational and fully checked out.

##### 4.1.1 Analytical Instruments and Related Equipment

The analytical system consists of five instruments and associated equipment for simultaneously measuring the composition of the flue gas. The analyzers, recorders, valves, controls, and manifolds are mounted on a panel in the vehicle. The analyzers are shock mounted to prevent vibration damage. The flue gas constituents which are measured are oxides of nitrogen (NO, NO<sub>x</sub>), carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), oxygen (O<sub>2</sub>), and gaseous hydrocarbons (HC).

Listed below are the measurement parameters, the analyzer model furnished, and the range and accuracy of each parameter for the system. A detailed discussion of each analyzer follows:

- Nitric Oxide/total oxides of nitrogen (NO/NO<sub>x</sub>)  
Thermo Electron Model 10 Chemiluminescent Analyzer  
Range: 0-2.5, 10, 25, 100, 250, 1000, 2500, 10,000 ppm NO  
Accuracy:  $\pm 1\%$  of full scale

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- Carbon Monoxide  
Beckman Model 315B NDIR Analyzer  
Range: 0-500 and 0-2000 ppm CO  
Accuracy:  $\pm 1\%$  of full scale

- Carbon Dioxide  
Beckman Model 864 NDIR Analyzer  
Range: 0-5% and 0-20% CO<sub>2</sub>  
Accuracy:  $\pm 1\%$  of full scale

- Oxygen  
Teledyne Model 326A Fuel Cell Analyzer  
Range: 0-5, 10 and 25% O<sub>2</sub> full scale  
Accuracy:  $\pm 1\%$  of full scale

- Hydrocarbons  
Beckman Model 402 Flame Ionization Analyzer  
Range: 5 ppm full scale to 10% full scale  
Accuracy:  $\pm 1\%$  of full scale

The oxides of nitrogen monitoring instrument used is a Thermo Electron chemiluminescent nitric oxide analyzer. The operational basis of the instrument is the chemiluminescent reaction of NO and O<sub>3</sub> to form NO<sub>2</sub>. Light emission results when electronically excited NO<sub>2</sub> molecules revert to their ground state. This resulting chemilunescence is monitored through an optical filter by a high sensitivity photomultiplier, the output of which is linearly proportional to the NO concentration.

Air for the ozonator is drawn from ambient through an air dryer and a ten micrometer filter element. Flow control for the instrument is accomplished by means of a small bellows pump mounted on the vent of the instrument downstream of a separator which insures that no water collects in the pump.

The basic analyzer is sensitive only to NO molecules. To measure NO<sub>x</sub> (i.e., NO+NO<sub>2</sub>), the NO<sub>2</sub> is first converted to NO. This is accomplished by a converter which is included with the analyzer. The conversion occurs as the gas passes through a thermally insulated, resistance heated, stainless steel coil. With the application of heat, NO<sub>2</sub> molecules in the sample gas are reduced to NO molecules, and the analyzer now reads NO<sub>x</sub>. NO<sub>2</sub> is obtained by the difference in readings obtained with and without the converter in operation.

Specifications: Accuracy 1% of full scale

Span Stability ±1% of full scale in 24 hours

Zero Stability ±1 ppm in 24 hours

Power Requirements 115±10V, 60 Hz, 1000 watts

Response 90% of full scale in 1 sec. (NO<sub>x</sub> mode),  
0.7 sec NO mode

Output 4-20 ma

Sensitivity 0.5 ppm

Linearity ±1% of full scale

Vacuum detector operation

Range: 2.5, 10, 25, 100, 250, 1000, 2500, 10,000  
ppm full scale

Carbon Monoxide concentration is measured by a Beckman 315B non-dispersive infrared analyzer. This instrument measures the differential in infrared energy absorbed from energy beams passed through a reference cell (containing a gas selected to have minimal absorption of infrared energy in the wavelength absorbed by the gas component of interest) and a sample cell through which the sample gas flows continuously. The differential absorption appears as a reading on a scale from 0 to 100 and is then related to the concentration of the specie of interest by calibration curves supplied with the instrument. The operating ranges for the CO analyzer are 0-500 and 0-2000 ppm.

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Specifications: Span Stability  $\pm 1\%$  of full scale in 24 hours  
Zero Stability  $\pm 1\%$  of full scale in 24 hours  
Ambient Temperature Range 32°F to 120°F  
Line Voltage 115  $\pm$  15 V rms  
Response: 90% of full scale in 0.5 or 2.5 sec.  
Precision:  $\pm 1\%$  of full scale  
Output: 4-20 ma

Carbon Dioxide concentration is measured by a Beckman Model 864 short path-length, non-dispersive infrared analyzer. This instrument measures the differential in infrared energy absorbed from energy beams passed through a reference cell (containing a gas selected to have minimal absorption of infrared energy in the wavelength absorbed by the gas component of interest) and a sample cell through which the sample gas flows continuously. The differential absorption appears as a reading on a scale from 0 to 100 and is then related to the concentration of the specie of interest by calibration curves supplied with the instrument. The operating ranges for the CO<sub>2</sub> analyzer are 0-5% and 0-20%.

Specifications: Span Stability  $\pm 1\%$  of full scale in 24 hours  
Zero Stability  $\pm 1\%$  of full scale in 24 hours  
Ambient Temperature Range 32°F to 120°F  
Line Voltage 115  $\pm$  15 V rms  
Response; 90% of full scale in 0.5 or 2.5 sec.  
Precision;  $\pm 1\%$  of full scale  
Output: 4-20 ma

The Oxygen content of the flue gas sample is automatically and continuously determined with a Teledyne Model 326A Oxygen analyzer. Oxygen in the flue gas diffuses through a Teflon membrane and is reduced on the surface of the cathode. A corresponding oxidation occurs at the anode internally and an electric current is produced that is proportional to the concentration of oxygen. This current is measured and conditioned by the instrument's electronic circuitry to give a final output in percent O<sub>2</sub> by volume for operating ranges of 0% to 5%, 0% to 10%, or 0% to 25%.

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Specifications: Precision:  $\pm 1\%$  of full scale  
Response: 90% in less than 40 sec.  
Sensitivity: 1% of low range  
Linearity:  $\pm 1\%$  of full scale  
Ambient Temperature Range: 32-125°F  
Fuel cell life expectancy: 40,000-hrs.  
Power Requirement: 115 VAC, 50-60 Hz, 100 watts  
Output: 4-20 ma

Hydrocarbons are measured using a Beckman Model 402 hydrocarbon analyzer which utilizes the flame ionization method of detection. The sample is drawn through a heated line to prevent the loss of higher molecular weight hydrocarbons to the analyzer. It is then filtered and supplied to the burner by means of a pump and flow control system. The sensor, which is the burner, has its flame sustained by regulated flows of fuel (40% hydrogen + 60% helium) and air. In the flame, the hydrocarbon components of the sample undergo a complete ionization that produces electrons and positive ions. Polarized electrodes collect these ions, causing a small current to flow through an electronic measuring circuit. This ionization current is proportional to the concentration of hydrocarbon atoms which enter the burner. The instrument is available with range selection from 5 ppm to 10% full scale as CH<sub>4</sub>.

Specifications: Full scale sensitivity, adjustable from 5 ppm CH<sub>4</sub> to 10% CH<sub>4</sub>  
Ranges: Range multiplier switch has 8 positions: X1, X5, X10, X50, X100, X500, X1000, and X5000. In addition, span control provides continuously variable adjustment within a dynamic range of 10:1  
Response Time: 90% full scale in 0.5 sec.  
Precision:  $\pm 1\%$  of full scale  
Electronic Stability:  $\pm 1\%$  of full scale for successive identical samples  
Reproducibility:  $\pm 1\%$  of full scale for successive identical samples

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Analysis Temperature: Ambient

Ambient Temperature: 32°F to 110°F

Output: 4-20 ma

Air Requirements: 350 to 400 cc/min of clean, hydrocarbon-free air, supplied at 30 to 200 psig

Fuel Gas Requirements: 75 to 80 cc/min of pre-mixed fuel consisting of 40% hydrogen and 60% nitrogen or helium, supplied at 30 to 200 psig

Electrical Power Requirements: 120v, 60 Hz

Automatic Flame-out indication and fuel shut-off valve

#### 4.1.2 Recording Instruments

The output of the four analyzers are presented on front panel meters and are simultaneously recorded on a Texas Instrument Model FLO4W6D four-pen strip chart recorder. The recorder specifications are as follows:

Chart Size: 9-3/4 inch

Accuracy:  $\pm 0.25\%$

Linearity:  $< 0.1\%$

Line Voltage: 120V  $\pm 10\%$  at 60 Hz

Span Step Response: 1 second

#### 4.1.3 Gas Sampling and Conditioning System

The gas sampling and conditioning system consists of probes, sample line, valves, pumps, filters and other components necessary to deliver a representative, conditioned sample gas to the analytical instrumentation. The following sections describe the system and its components. The entire gas sampling and conditioning system shown schematically in Figure 4-1 is contained in the emission test vehicle.

#### 4.2 GASEOUS EMISSION SAMPLING TECHNIQUES (NOx, CO, CO<sub>2</sub>, O<sub>2</sub>, HC)

Boiler access points for gaseous sampling are selected in the same sample plant as are particulate sample points. Each probe consists of one-half inch 316 stainless steel heavy wall tubing. A 100 micrometer Mott Metallurgical Corp. sintered stainless steel filter is attached to each probe for removal of particulate material.



Gas samples to be analyzed for  $O_2$ ,  $CO_2$ , CO and NO are conveyed to the KVB mobile laboratory through 3/8 inch nylon sample lines. After passing through bubblers for flow control, the samples pass through a diaphragm pump and a refrigerated dryer to reduce the sample dew point temperature to 35°F. After the dryer, the sample gas is split between the various continuous gas monitors for analysis. Flow through each continuous monitor is accurately controlled with rotometers. Excess flow is vented to the outside. Gas samples are drawn sequentially from all probes for each test. The average emission values are reported in this report.

#### 4.3 SULFUR OXIDES ( $SO_x$ ) MEASUREMENT AND PROCEDURE

Measurement of  $SO_2$  and  $SO_3$  concentrations are made by wet chemical analysis using the "Shell-Emeryville" method. In this technique the gas sample is drawn from the stack through a glass probe (Figure 4-2), containing a quartz wool filter to remove particulate matter, into a system of three sintered glass plate absorbers (Figure 4-3). The first two absorbers contain aqueous isopropyl alcohol and remove the sulfur trioxide; the third contains aqueous hydrogen peroxide solution which absorbs the sulfur dioxide. Some of the sulfur trioxide is removed by the first absorber, while the remainder, which passes through as a sulfuric acid mist, is completely removed by the secondary absorber mounted above the first. After the gas sample has passed through the absorbers, the gas train is purged with nitrogen to transfer sulfur dioxide, which has dissolved in the first two absorbers, to the third absorber to complete the separation of the two components. The isopropyl alcohol is used to inhibit the oxidation of sulfur dioxide to sulfur trioxide before it gets to the third absorber.

The isopropyl alcohol absorber solutions are combined and the sulfate resulting from the sulfur trioxide absorption is titrated with standard lead perchlorate solution using Sulfonazo III indicator. In a similar manner, the hydrogen peroxide solution is titrated for the sulfate resulting from the sulfur dioxide absorption.

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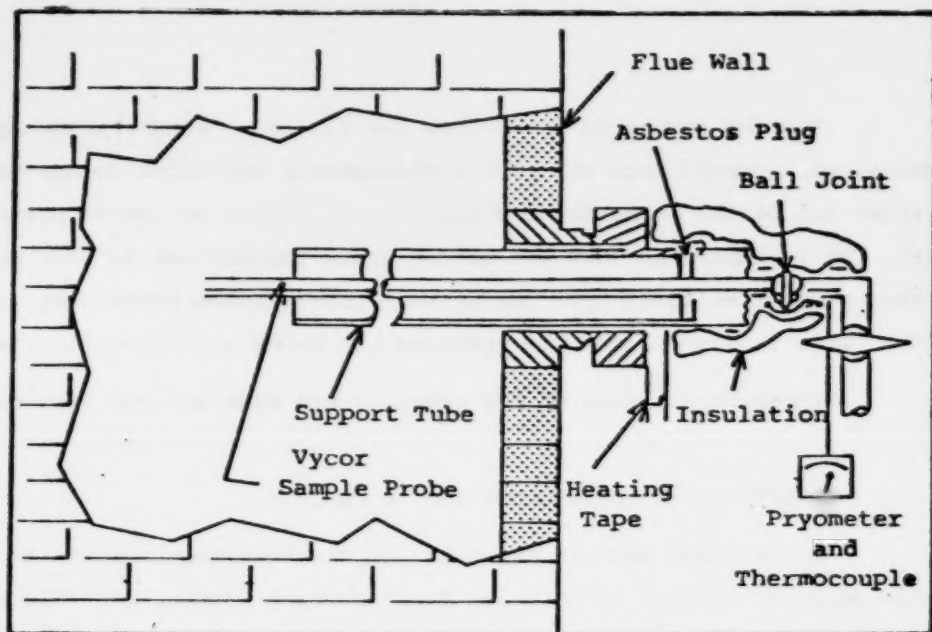


Figure 4-2. SOx Sample Probe Construction

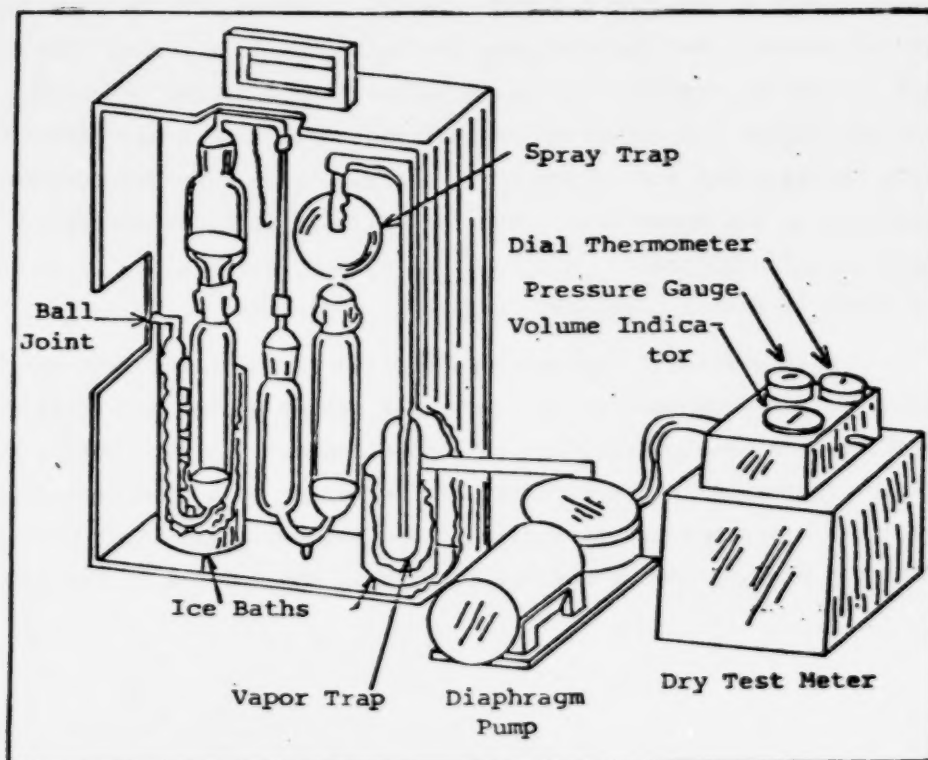


Figure 4-3. Sulfur Oxides Sampling Train

The gas sample is drawn from the flue by a single probe made of quartz glass inserted into the duct approximately one-third to one-half way. The inlet end of the probe holds a quartz wool filter to remove particulate matter. It is important that the entire probe temperature be kept above the dew point of sulfuric acid during sampling (minimum temperature of 260°C). This is accomplished by wrapping the probe with a heating tape.

Three repetitions of SO<sub>x</sub> sampling are made at each test point.

#### 4.4 PARTICULATES MEASUREMENT AND PROCEDURES

Particulate samples are taken at the same sample ports as the gaseous emission samples using a Joy Manufacturing Company portable effluent sampler (Figure 4-4). This system, which meets the EPA design specifications for Test Method 5, Determination of Particulate Emissions from Stationary Sources (Federal Register, Volume 36, No. 27, page 24888, December 23, 1971), is used to perform both the initial velocity traverse and the particulate sample collection. Dry particulates are collected in a heated case using first a cyclone to separate particles larger than 5 micrometers and a 100 mm glass fiber filter for retention of particles down to 0.3 micrometers. Condensible particulates are collected in a train of four Greenburg-Smith impingers in an ice water bath. The control unit includes a total gas meter and thermocouple indicator. A pitot tube system is provided for setting sample flows to obtain isokinetic sampling conditions.

All peripheral equipment is carried in the instrument van. This includes a scale (accurate to  $\pm 0.1$  mg), hot plate, drying oven (212°F), high temperature oven, desiccator, and related glassware. A particulate analysis laboratory is set up in the vicinity of the boiler in a vibration-free area. Here filters are prepared, tare weighed and weighed again after particulate collection. Also, probe washes are evaporated and weighed in the lab.

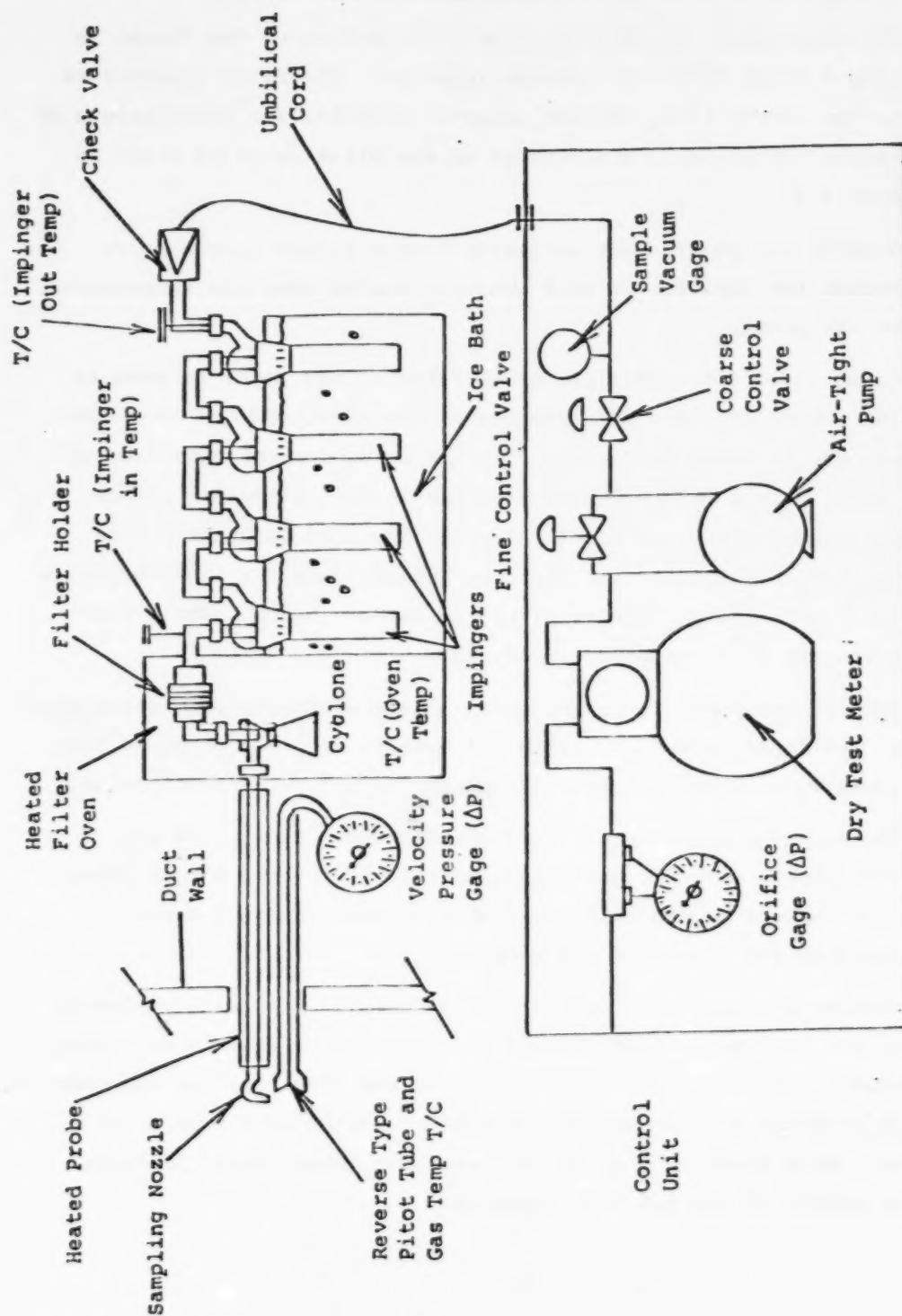


Figure 4-4. Particulate sampling train.

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The measurement of particle size distribution of the flyash is performed using a Brink Model "B" Cascade impactor. The Brink impactor is a five stage, low sample rate, cascade impactor suitable for measurements in high mass loading situations. A schematic of the Brink sampling train is shown in Figure 4-5.

Samples are pulled isokinetically from a single sample point. The flow rate through the impactor is held constant during sampling to preserve the impaction cut points.

Gelman type A-E binderless glass fiber filter paper is used as the collection substrate. The main purpose of the glass mats is to reduce re-entrainment due to particle bounce. The 5/8 inch diameter mats are cut from larger stock with a cork bore and inserted in the collection plates. The collection plates with mats installed are desiccated 24 hours before tare weighing. After sampling, all particles adhering to the impactor walls are brushed down onto the collection plate immediately below. The plates are again desiccated 24 hours before weighing.

The cyclone catch is brushed onto a tare weighed paper, desiccated and weighed. The final filter, cut from the same fiber glass stock as the collection plate substrates, is treated the same as the collection plates.

The sampling procedure is straight forward. First, the gas velocity at the sample point is determined using a calibrated S-type pitot tube. For this purpose a hand held particulate probe, inclined manometer, thermocouple and indicator are used.

Second, a nozzle size is selected which will maintain isokinetic flow rates within the recommended .02-.07 ft<sup>3</sup>/min rate at stack conditions. Having selected a nozzle and determined the required flow rate for isokinetics, the operating pressure drop across the impactor is determined from a calibration curve. This pressure drop is corrected for temperature, pressure and molecular weight of the gas to be sampled.

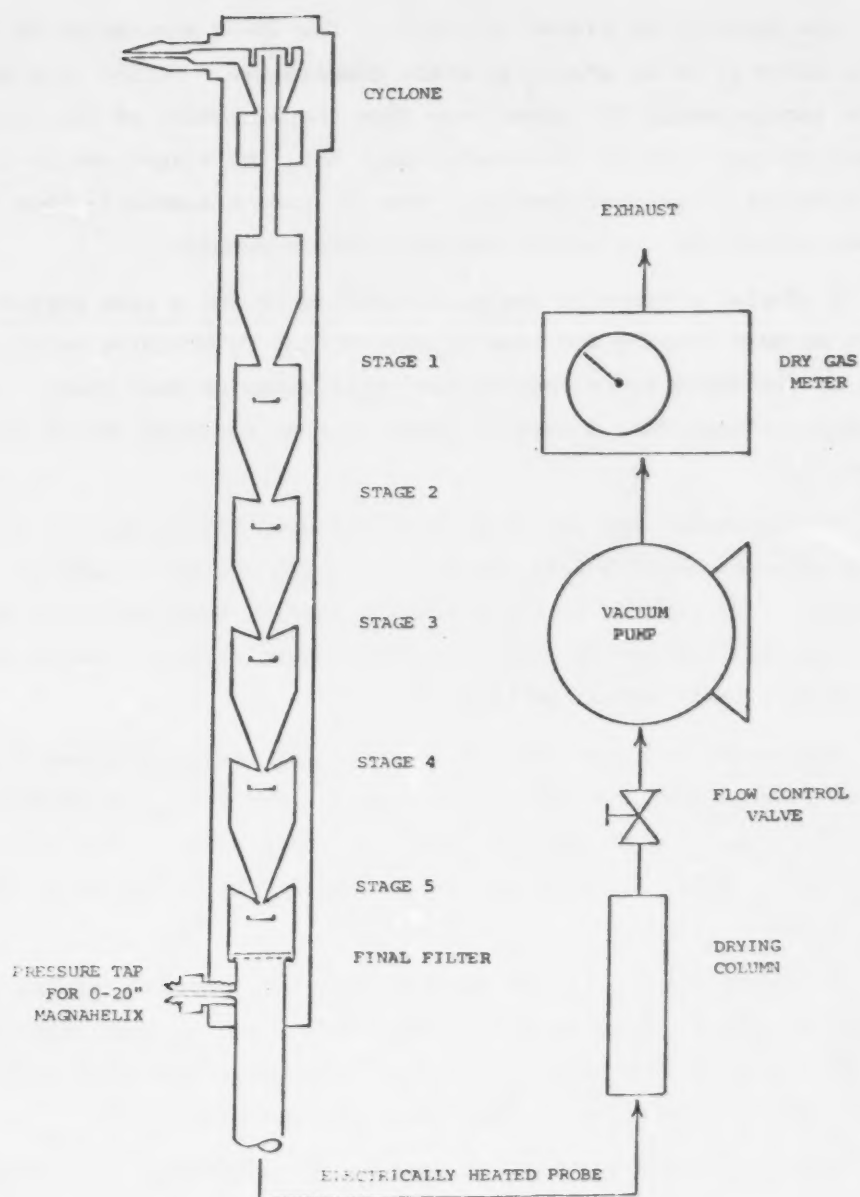


Figure 4-5. Brink cascade impactor sampling train schematic.

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The impactor is placed in the duct for 20-30 minutes prior to sampling to allow it to be heated to stack temperature. During this warmup period, the sample nozzle is turned away from the direction of gas flow so that no particulates will be collected. Once hot, the stages are re-tightened with pipe wrenches to prevent leakage. The impactor's nozzle is then turned into the gas stream for collecting the particulate sample.

A sample is drawn at the predetermined  $\Delta P$  for a time period which is dictated by mass loading and size distribution. To minimize weighing errors, it is desirable to collect several milligrams on each stage. However, to minimize re-entrainment, a rule of thumb is that no stage should be loaded above 10 mg.

The volume of dry gas sampled is measured with a dry gas meter. This allows calculation of actual isokinetics. The dry gas volume is also used to convert test results to concentration units. Stack moisture used for calculating isokinetics is measured with the EPA Method 5 sample train during concurrent particulate sampling.

Data reduction involves a time-consuming iterative process and is best accomplished with the aid of a computer. For this purpose KVB developed a 223 step program for the Texas Instruments SR-52 card programmable calculator. With this program, Brink data reduction can be easily done in the field.

In addition to the Brink Cascade Impactor, particle sizing is accomplished by several other methods. The SASS train utilizes three sized cyclones and a final filter under controlled temperature and flow rates to achieve gravimetric separation at ten, three and one micrometers.

Selected flyash samples are sent to an independent laboratory for sizing using the BAHCO centrifugal classifier (PTC 28).

Each of the three particle sizing methods described above has its advantages and disadvantages. None is ideal for the intended application.

Bahco - The Bahco classifier is described in Power Test Code 28. It is an acceptable particle sizing method in the power industry and is often used in specifying mechanical dust collector guarantees. Its main disadvantage is that it is a laboratory technique and is thus only as accurate as the sample collected. Most Bahco samples are collected by cyclone separation; thus, particles below the cut point of the cyclone are lost. The Bahco samples collected at Test Site B came from the cyclone in the EPA Method 5 particulate train. These samples are spatially representative because they were taken from a 24-point sample matrix. However, much of the sample below about seven micrometers was lost to the filter. The Bahco test data are presented in combination with sieve analysis of the same sample. No attempt was made to correct for the lost portion of the sample.

Brink - The Brink cascade impactor is an in-situ particle sizing device which separates the particles into six size classifications. It has the advantage of collecting the entire sample. That is, everything down to the collection efficiency of the final filter is included in the analysis. Its disadvantages for this application are great. Because it is a single point sampler, spatial stratification of particulate matter within the duct will yield erroneous results. Unfortunately, the particles at the outlets of stoker boilers may be considerably stratified. Another disadvantage is its small classification range (0.3 to 3.0 micrometers) and its small sample nozzle (1.5 to 2.0 mm maximum diameter). Both are inadequate for the job at hand. The particles being collected at the boiler outlet are often as large as the sample nozzle.

SASS - The Source Assessment Sampling System (SASS) was not designed principally as a particle sizer but it includes three calibrated cyclones which are used as such. The SASS train is a single point in-situ sampler. Thus, it is on a par with cascade impactors. Because it is a high volume sampler and samples are drawn through large nozzles (0.25 to 1.0 in.), it has an advantage over the Brink cascade impactor where large particles are involved. The cut points of the three cyclones are 10, 3 and one micrometers.

#### 4.6

#### COAL SAMPLING AND ANALYSIS PROCEDURE

Coal samples are taken during each test from the units two coal scales. The samples are processed and analyzed for both size consistency and chemical composition. The use of the coal scale as a sampling station has two advantages. It is close enough to the furnace that the coal sampled simultaneously with testing is representative of the coal fired during the testing. Also, because of the construction of the coal scale, it is possible to collect a complete cut of coal off the scales apron feeder thus insuring a representative size consist.

In order to collect representative coal samples, a sampling tray having a twenty pound capacity was custom built. The tray has the same width as the apron feeder belt and can be moved directly under the belts discharge end to catch all of the coal over a short increment of time (approximately five seconds).

Sampling procedure is as follows. At the start of testing one increment of sample is collected from each feeder. This is repeated twice more during the test (three to five hours duration) so that a six increment sample is obtained. The sample is then riffled using a Gilson Model SP-2 Porta Splitter until two representative twenty pound samples are obtained.

The sample to be used for sieve analysis is weighed, dried in an oven at 220°F for about four hours, and re-weighed. Drying of the coal is necessary for good separation. If the coal is wet, fines cling to the larger pieces of coal and to each other. Coal moisture removed by drying represented 4-8 percent of the "as-fired" weight. Once dry, the coal is sized using a six tray Gilson Model PS-3 Porta Screen. Screen sizes used are 1", 1/2", 1/4", #8 and #16 mesh. Screen area per tray is 14"x14". The coal in each tray is weighed on a triple beam balance to the nearest 0.1 gram.

The coal sample for chemical analysis is reduced to 2-3 pounds by further riffling and sealed in a plastic bag. All coal samples are sent to Commercial Testing and Engineering Company, South Holland, Illinois. Each sample associated with a particulate loading or particle sizing test is given a proximate analysis. In addition, selected samples receive ultimate analysis, ash fusion temperature and mineral analysis of the ash.

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During selected tests, coal samples composed of thirty-six increments of six pounds each were collected along with the normal six increment samples. These tests, reported in the appendix, demonstrated that six increment samples were adequate for our purposes.

#### 4.7 ASH COLLECTION AND ANALYSIS FOR COMBUSTIBLES

Combustible content of flyash is determined in the field by KVB in accordance with ASTM D3173, "Moisture in the Analysis Sample of Coal and Coke" and ASTM D3174, "Ash in the Analysis Sample of Coal and Coke."

The flyash sample is collected by the EPA Method 5 particulate sample train while sampling for particulates. The cyclone catch is placed in a desiccated and tare weighed ceramic crucible. The crucible with sample is heated in an oven at 230°F to remove its moisture. It is then desiccated to room temperature and weighed. The crucible with sample is then placed in an electric muffle furnace maintained at a temperature of 1400°F until ignition is complete and the sample has reached a constant weight. It is cooled in a desiccator over desiccant and weighed. Combustible content is calculated as the percent weight loss of the sample based on its post 230°F weight.

Bottom ash samples are collected from the bottom ash hopper within two hours after completion of each test. The ash hopper is cleared just prior to the test to insure that the hopper contains only ash generated during the test. Four five-pound samples are collected representing a cross-section of the ash hopper. These samples are mixed, quartered, and sent to Commercial Testing and Engineering Company for combustible determination.

Multiclone ash samples are taken from four ports near the bottom of the hopper into which the multiclone ash is dumped prior to being discarded. This sample, approximately two quarts in size, is sent to Commercial Testing and Engineering Company for combustible determination.

#### 4.8 BOILER EFFICIENCY EVALUATION

Boiler efficiency is calculated using the ASME Test Form for Abbreviated Efficiency Test, Revised, September, 1965. The general approach to efficiency evaluation is based on the assessment of combustion losses. These losses can be grouped into three major categories: stack gas losses, combustible losses, and radiation losses. The first two groups of losses are measured directly. The third is estimated from the ABMA Standard Radiation Loss Chart.

Unlike the ASME test form where combustible losses are lumped into one category, combustible losses are calculated and reported separately for combustibles in the bottom ash, combustibles in the mechanically collected ash which is not reinjected, and combustibles in the flyash leaving the mechanical collector.

KVB has developed a program for the Texas Instrument's SR-52 card programmable calculator to compute the above heat losses. Use of this program helps minimize human error in the calculations.

#### 4.9 MODIFIED SMOKE SPOT NUMBER

Modified Bacharach smoke spot numbers are determined using a Bacharach field service type smoke tester. ASTM procedures for this measurement apply only to oil fired units. Therefore, KVB has defined its own set of procedures which differ from ASTM D2156-65 procedure in the number of strokes taken with the hand pump. At this test site, one and two strokes were taken at the boiler outlet.

Smoke spot measurements are obtained by pulling a fixed volume of flue gas through a standard filter paper. The color (or shade) of the spot that is produced is matched visually with a standard smoke spot scale. The result is a "Smoke Number" which is used to characterize the density of smoke in the flue gas.

The sampling device is a hand pump similar to the one shown in Figure 4-6. It is a commercially available item that with ten strokes can pass 2,250  $\pm$  100 cubic inches of gas at 60°F and 1 atmosphere pressure through an enclosed filter paper for each 1.0 square inch effective surface area of the filter paper.

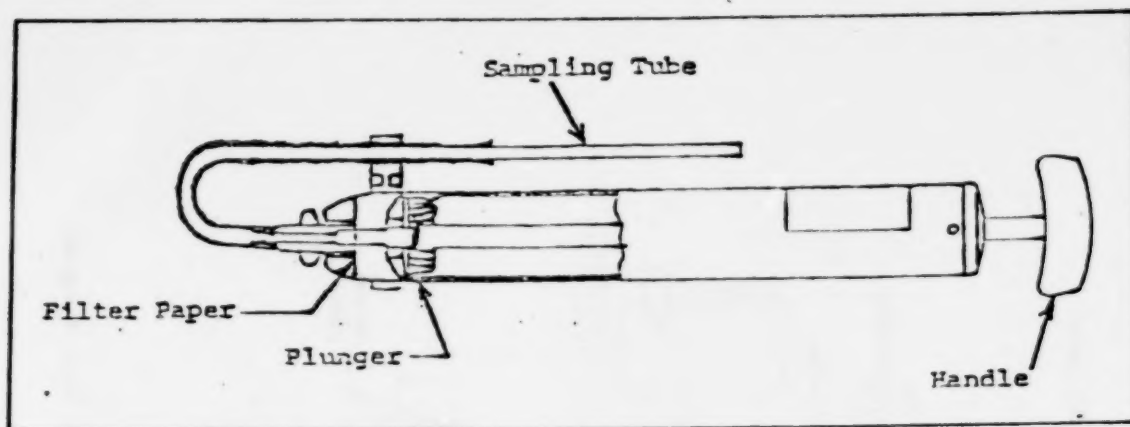


Figure 4-6. Field Service Type Smoke Tester

The standard smoke scale consists of a series of ten spots numbered consecutively from 0 to 9, and ranging in equal photometric steps from white through neutral shades of gray to black. The standard spots are imprinted on white paper having an absolute surface reflectance of between 82.5 and 87.5%, determined photometrically. The smoke scale spot number is defined as the reduction (due to smoke) in the amount of light reflected by a spot divided by 10.

The smoke density is reported as the Smoke Spot Number of the spot on the standard smoke scale that most closely corresponds to the color of the soiled spot on the sample filter paper. Differences between two standard Smoke Spot Numbers are interpolated to the nearest half number.

#### 4.10 TRACE SPECIES MEASUREMENT

The EPA (IERL-RTP) has developed the Source Assessment Sampling System (SASS) train for the collection of particulate and volatile matter in addition to gaseous samples (Figure 4-7). The "catch" from the SASS train is analyzed for polynuclear aromatic hydrocarbons (PAH) and inorganic trace elements.

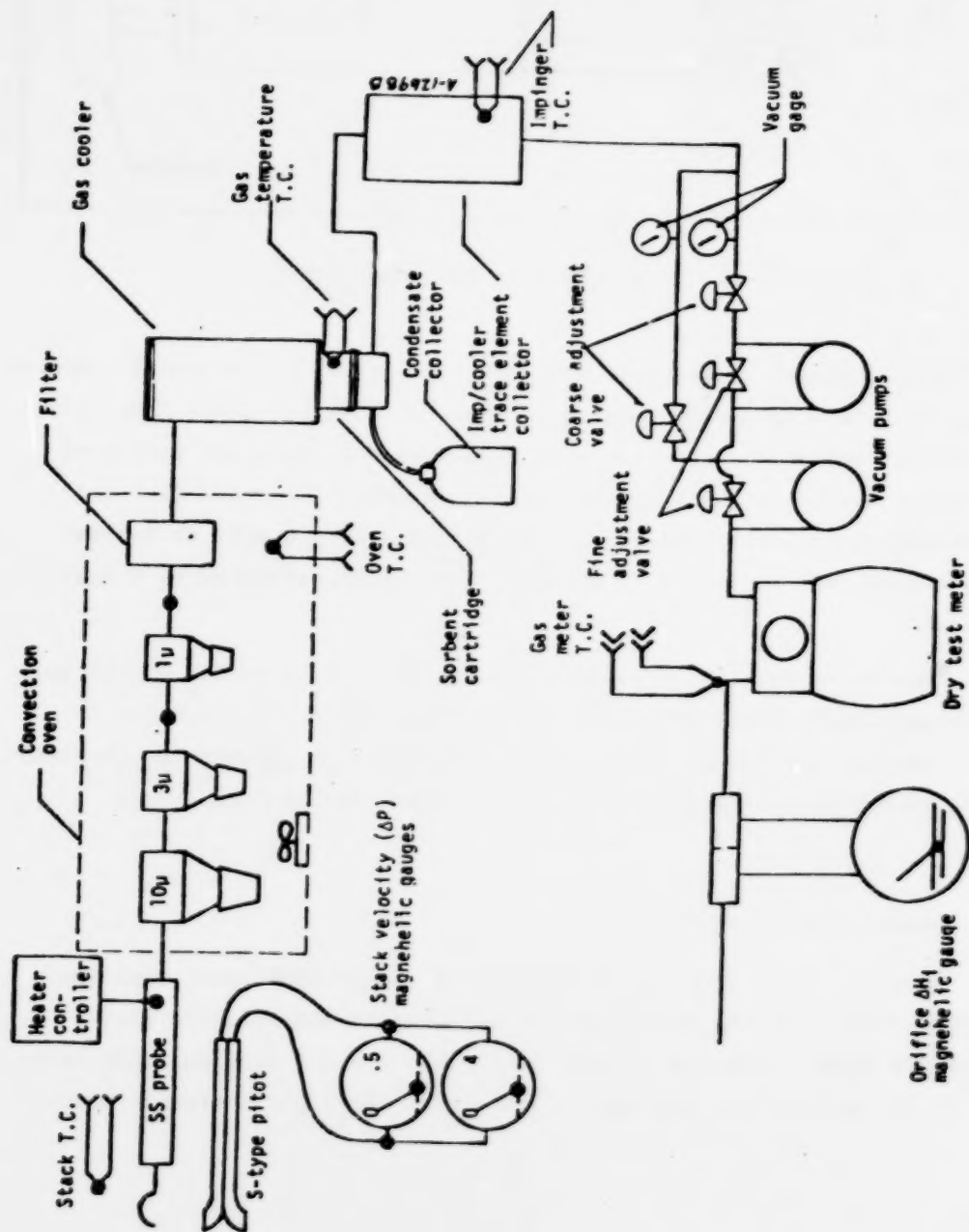


Figure 4-7. Source Assessment Sampling System (SASS) flow diagram.

In this system, a stainless steel heated probe is connected to an oven module containing three cyclones and a filter. Size fractionation is accomplished in the series cyclone portion of the SASS train, which incorporates the cyclones in series to provide large quantities of particulate matter which are classified by size into three ranges:

- A)  $>10\ \mu\text{m}$       B)  $3\ \mu\text{m}$  to  $10\ \mu\text{m}$       C)  $1\ \mu\text{m}$  to  $3\ \mu\text{m}$

Together with a filter, a fourth cut ( $<1\ \mu\text{m}$ ) is obtained. Volatile organic material is collected in an XAD-2 sorbent trap. The XAD-2 trap is an integral part of the gas treatment system which follows the oven containing the cyclone system. The gas treatment system is composed of four primary components: the gas conditioner, the XAD-2 absorbent trap, the aqueous condensate collector, and a temperature controller. The XAD-2 sorbent is a porous polymer resin with the capability of absorbing a broad range of organic species. Some trapping of volatile inorganic species is also anticipated as a result of simple impaction. Volatile inorganic elements are collected in a series of impingers. The pumping capacity is supplied by a 10 cfm high volume vacuum pump, while required pressure, temperature, power and flow conditions are obtained from a main controller.

#### 4.11 FLYASH RESISTIVITY MEASUREMENT

The Wahlco Resistivity Probe is an in situ field device for use in investigating problems with electrostatic precipitators. The means of collection is mechanical so no dust characteristics are destroyed during the sampling process. The probe can be used in temperatures up to  $450^{\circ}\text{F}$ . An integral cleaning system allows repeated tests in a single location without removing the probe from the duct. All instrumentation and probe hardware are contained in a single carrying case suitable as a shipping container.

The Resistivity Probe consists of a small cyclone inserted in the duct which collects a dust sample in a cylindrical stainless steel cup. A high voltage discharge pin mounted axially and electrically insulated from the cup serves as the energizing electrode. The steel cup serves as the receiver. The high voltage supply is held at 1,000 volts and resistivity of the collected sample is then determined as a function of the current.

An integral cleaning system permits emptying of the cup without removing the probe from the duct. Air is blown through a separate tube to a purge coil and then into the bottom of the cup, thus discharging the dust back into the flue gas stream. The purpose of the purge coil is to pre-heat incoming air to prevent condensation in the cup.

## SECTION 5.0

### TEST RESULTS AND OBSERVATIONS

This section presents the results of the tests performed on Boiler B. Observations are made regarding the influence on gaseous and particulate emissions and efficiency as the control parameters were varied. A total of 33 tests were conducted in a defined test matrix to develop this data. Data summary tables 5-10 through 5-19 are included at the end of this section for reference.

#### 5.1 OVERFIRE AIR

Overfire air flow rate was varied during four test sets to measure this parameter's effects on boiler emissions and efficiency. Increasing the rear overfire air flow resulted in reduced particulate emissions and increased boiler efficiency. Gaseous emissions were not significantly affected. Therefore, overfire air was demonstrated to be an effective emission control technology for particulate emissions only, over the limited range of conditions tested. These tests and their results are described in detail below. Test conditions and results are summarized in Table 5-1.

As an initial step in understanding the overfire air system, its air flow rate was measured and related to duct static pressure at two air flow conditions. This information was then used to form the graph (Figure 5-1) relating overfire air flow in lb/min to static pressure at all flow conditions. The basis for this relationship is Bernoulli's equation for fluid flow through an orifice (in this case, the overfire air jets). One form of Bernoulli's equation is:

$$\frac{\Delta P}{\rho} = \frac{\Delta v^2}{2g}$$

Here,  $\Delta P$  is the pressure drop across an orifice,  $\rho$  is the fluid density,  $\Delta v^2$  is the change in fluid velocity and  $g$  is the gravitational constant. In this relationship, velocity ( $v$ ) is proportional to the square root of the

TABLE 5-1. EFFECT OF OVERFIRE AIR  
ON EMISSIONS AND EFFICIENCY

| TEST NO.                                                    | Set 1      |            | Set 2      |            | Set 3      |            |
|-------------------------------------------------------------|------------|------------|------------|------------|------------|------------|
|                                                             | Min<br>OFA | Max<br>OFA | Min<br>OFA | Max<br>OFA | Min<br>OFA | Max<br>OFA |
| <u>OVERFIRE AIR CONDITIONS</u>                              |            |            |            |            |            |            |
| Front OFA Pressure, "H <sub>2</sub> O (upper/lower)         | 8/5        | 8/5        | 8/5        | 8/5        | 8/5        | 8/20       |
| Rear OFA Pressure, "H <sub>2</sub> O (upper/lower)          | 5/11       | 27/29      | 5/10       | 24/27      | 27/29      | 24/27      |
| Overfire Air Flow, lb/min                                   | 713        | 925        | 712        | 903        | 923        | --         |
| Overfire Air, % of Total Air                                | 24         | 31         | 19         | 24         | 24         | --         |
| <u>FIRING CONDITIONS</u>                                    |            |            |            |            |            |            |
| Coal Supplier*                                              | R          | R          | H          | H          | KC         | KC         |
| Load, % of Capacity                                         | 49         | 48         | 72         | 73         | 79         | 81         |
| Grate Heat Release, 10 <sup>3</sup> BTU/ft <sup>2</sup> /hr | 400        | 377        | 564        | 557        | 576        | 601        |
| Coal Sizing, % passing 1/4"                                 | 27         | 19         | 36         | 21         | 20         | 23         |
| Excess Air, %                                               | 59         | 69         | 41         | 46         | 42         | 43         |
| <u>BOILER OUTLET EMISSIONS</u>                              |            |            |            |            |            |            |
| Particulate Loading, lb/10 <sup>6</sup> BTU                 | 9.6        | 7.2        | 12.3       | 9.2        | 11.7       | 10.0       |
| Combustible Loading, lb/10 <sup>6</sup> BTU                 | 6.0        | 4.6        | 6.5        | 5.1        | 6.7        | 7.0        |
| Inorganic Ash Loading, lb/10 <sup>6</sup> BTU               | 3.6        | 2.6        | 5.7        | 4.1        | 5.0        | 3.0        |
| Combustibles in Flyash, %                                   | 62.6       | 64.0       | 53.3       | 55.2       | 57.3       | 70.3       |
| O <sub>2</sub> , % (dry)                                    | 8.0        | 8.8        | 6.3        | 6.8        | 6.4        | 6.5        |
| CO, ppm (dry) @ 3% O <sub>2</sub>                           | 36         | 96         | 103        | 34         | 44         | 47         |
| NO, ppm (dry) @ 3% O <sub>2</sub>                           | 280        | 339        | 209        | 310        | 311        | 305        |
| <u>MULTICLONE OUTLET EMISSIONS</u>                          |            |            |            |            |            |            |
| Particulate Loading, lb/10 <sup>6</sup> BTU                 | 0.50       | 0.48       | 0.82       | 0.62       | 0.59       | 0.34       |
| Combustible Loading, lb/10 <sup>6</sup> BTU                 | 0.12       | 0.16       | 0.24       | 0.16       | 0.17       | 0.10       |
| Inorganic Ash Loading, lb/10 <sup>6</sup> BTU               | 0.39       | 0.32       | 0.59       | 0.46       | 0.42       | 0.24       |
| Combustibles in Flyash, %                                   | 23.0       | 33.7       | 28.9       | 25.2       | 28.3       | 29.2       |
| Multiclone Collection Efficiency, %                         | 94.8       | 93.3       | 93.3       | 93.3       | 95.0       | 96.6       |
| <u>ECONOMIZER OUTLET</u>                                    |            |            |            |            |            |            |
| Flue Gas Temperature, °F                                    | 383        | 383        | 395        | 402        | 390        | 390        |
| <u>HEAT LOSSES, %</u>                                       |            |            |            |            |            |            |
| Combustibles in Multiclone Catch                            | 3.61       | 3.15       | 6.64       | 3.84       | 4.41       | 4.84       |
| Combustibles in Emitted Flyash                              | 0.17       | 0.25       | 0.39       | 0.26       | 0.30       | 0.16       |
| Combustibles in Bottom Ash                                  | 0.14       | 0.08       | 2.02       | 0.34       | 0.04       | 0.80       |
| Dry Gas Loss                                                | 8.80       | 9.63       | 7.61       | 8.82       | 8.05       | 7.68       |
| Boiler Efficiency                                           | 80.27      | 80.32      | 76.36      | 79.89      | 80.48      | 79.78      |

\* R - Reload  
H - Hatfield  
KC - Kentucky Cumberland

pressure drop ( $\Delta P$ ). Therefore, the overfire air flow rate in lb/min should be nearly proportional to the square root of the static pressure in the overfire air duct. The actual data for these calculations, and the formulas used are given in Table A and B of the Appendix.

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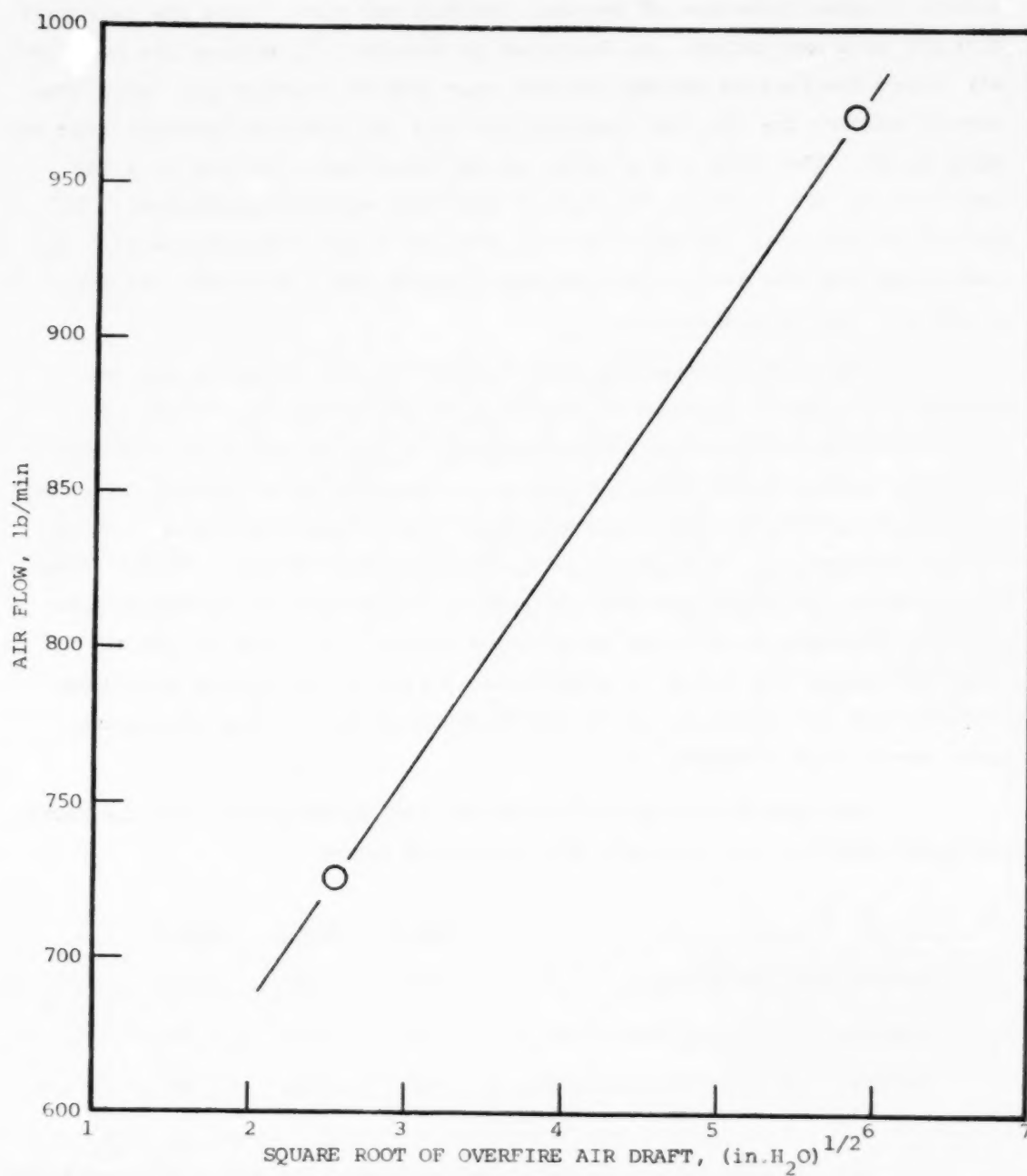


Figure 5-1. Overfire air flow vs. OFA draft reading.

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The air flow measurements were made with a S type pitot tube using a 24-point traverse of the main overfire air duct. Only the rear overfire air flow was varied. As described in Section 3.2, most of the overfire air enters the furnace through the two rear rows of overfire air jets. The control dampers for the rear overfire air jets are remotely operable from the panel board. The front row of jets, on the other hand, is set at a low level and is not normally adjusted by the plant operating personnel. All but one of the tests conducted on this unit (Test #28) were at overfire air conditions near the two directly measured conditions. This adds validity to the air flow determinations.

Particulate emissions were reduced 25% by increasing the rear overfire air flow as is shown in Figure 5-2. The reductions cannot be attributed solely to burnout of combustibles in the flyash since both combustibles and inorganic ash fractions were reduced proportionately the same. During test set three where the front lower underfeeder air/tuyere cooling air was increased, a 14.5% particulate reduction was measured. In this case, the reduction was completely attributable to a reduction in inorganic ash loading. Attempts to vary the front upper overfire air flow failed because the damper was frozen in position (a result of not having been used). A fourth test set (Tests 6 and 7) was rejected because firing conditions could not be held constant.

The reduction in particulates and its constituents for the three completed overfire air test sets are summarized below.

|                                     | <u>Set 1</u> | <u>Set 2</u> | <u>Set 3</u> |
|-------------------------------------|--------------|--------------|--------------|
| Particulate Reduction, %            | -25          | -25          | -14.5        |
| Combustible Fraction Reduction, %   | -23          | -22          | + 4.5        |
| Inorganic Ash Fraction Reduction, % | -28          | -28          | - 40         |

Nitric oxide emissions increased when overfire air flow through the rear of the furnace was increased, but this increase may not be statistically significant. The uncertainty, or scatter, in the data is graphically presented in Figures 5-3 and 5-4. Here, not only the overfire air test data but other test data under similar firing conditions is presented. When the front undergrate air flow was changed, the nitric oxide emissions remained unchanged.

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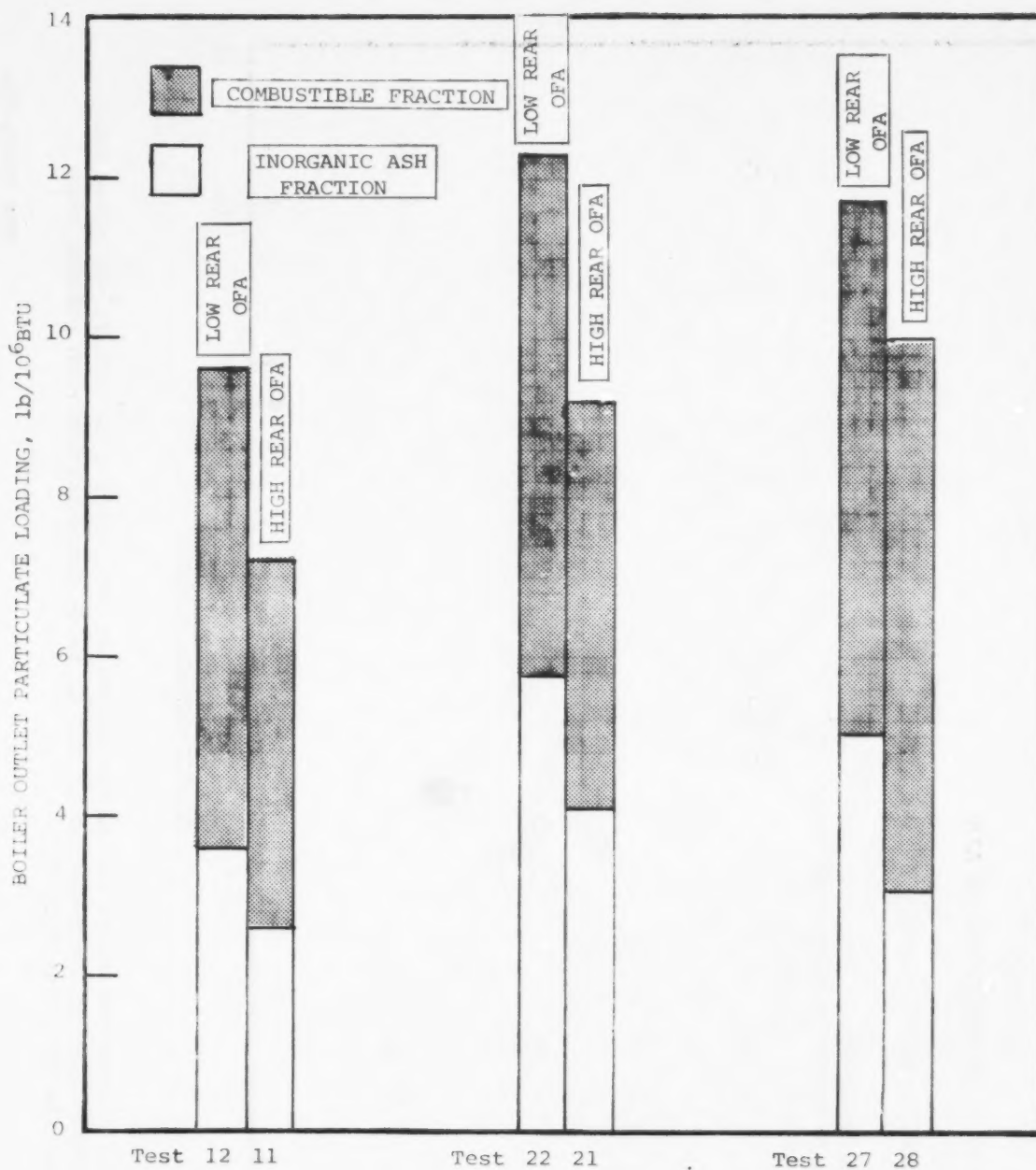


Figure 5-2. Particulate loading broken down into combustible and inorganic fractions for three overfire air test sets - Test Site B.



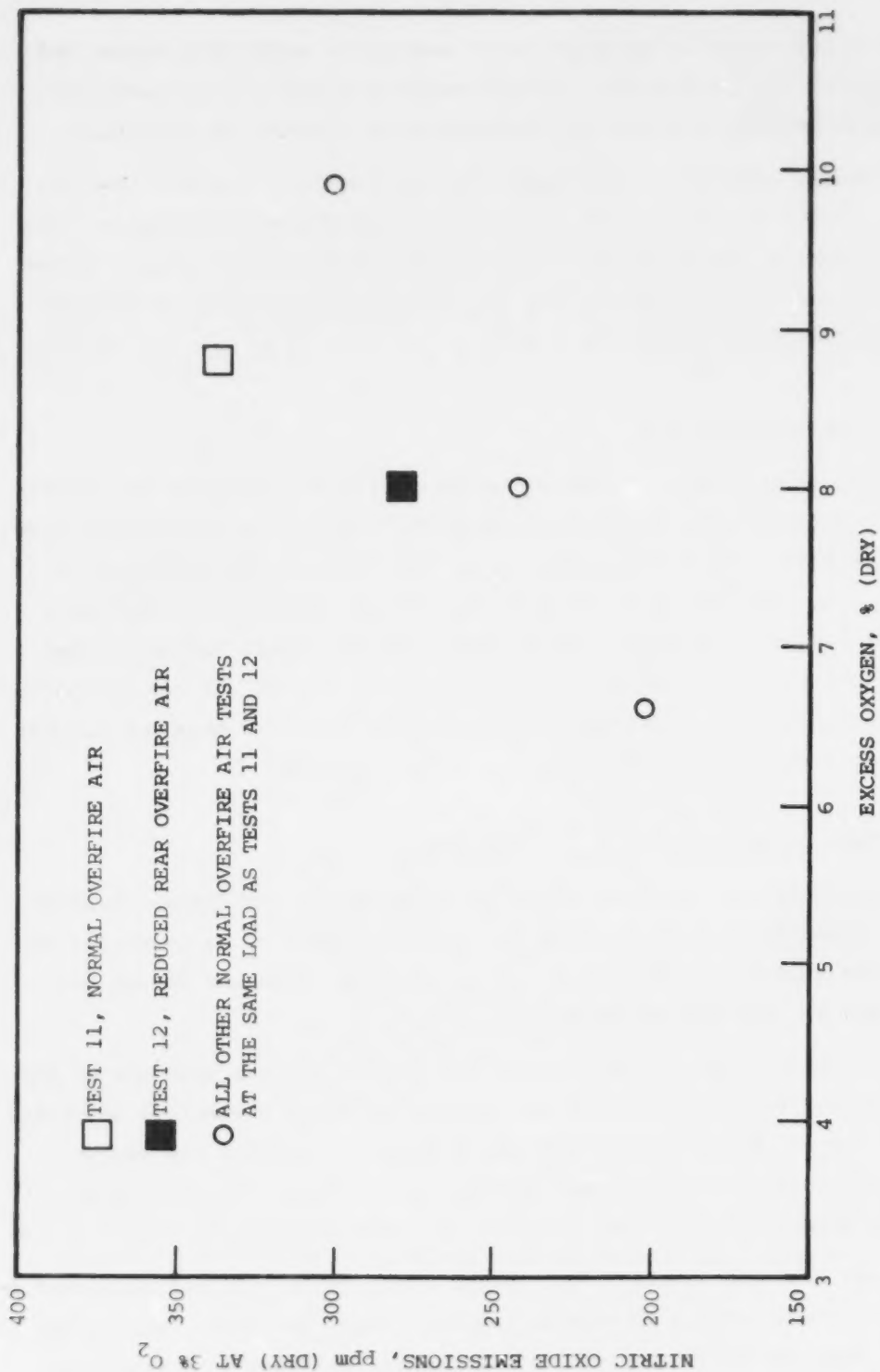


Figure 5-4. Nitric oxide emissions vs. excess oxygen at  $300$  to  $400 \times 10^3$  BTU/ft<sup>2</sup>-hr grate heat release showing no significant reduction in nitric oxide concentration when the rear overfire air flow is reduced - Test Site B.

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Carbon monoxide emissions were negligible under both normal and reduced overfire air conditions. Enough excess air and natural turbulence was present at reduced overfire air conditions to prevent its formation.

Boiler efficiency increased when the rear overfire air flow was increased. This increase was due to a decrease in combustible losses. The efficiency increase due to reduced combustible loading at the boiler outlet was 0.38% for set 1 and 2.93% for set 2. When the underfeeder air was increased, the efficiency decreased 0.29%.

## 5.2 FLYASH REINJECTION

Flyash reinjection from the mechanical dust collector was reduced 20% during one test to determine this parameter's effect on particulate loading, particle size distribution, and boiler efficiency. The reduction in reinjection rate resulted in a 39% reduction in particulate loading, and a 2.2% loss in boiler efficiency. Bahco sizing of the flyash indicated that the particulate reduction did not significantly affect the sub ten micrometer particle concentration. A reinjection rate measurement was made but did not produce results which would allow for a good ash balance.

### 5.2.1 Test 7, Reinjection Rate Measurement

Boiler B has no bypass valve or surge hopper for its reinjection system. In order to stop reinjection for test purposes, it is necessary to remove all the venturi sections from the reinjection lines and extend the hopper downspouts into sealed barrels.

During Test No. 7, an attempt was made to do this with one of the six boiler hopper reinjection lines and one of the seven mechanical collector reinjection lines. Difficulties were encountered in removing the venturi sections. Reinjection pressure was lost for approximately one-half hour, resulting in several of the other reinjection lines plugging up.

Ash from the single boiler hopper reinjection line was collected at a rate of 77.1 lb/hr over a three-hour period. Thus, the total rate of ash reinjection from the boiler hopper's six lines was calculated at 463 lb/hr. Certain errors could be expected in this measurement due to ash concentration

at one side of the hopper or various flow patterns. If the measured rate is representative of all six reinjection lines, then the boiler hopper removed fifteen percent of the boiler outlet flyash.

Ash from the single mechanical dust collector downspout was collected at a rate of 17.1 lb/hr over a 2-1/2 hour period. Thus, the total rate of ash reinjection from the mechanical dust collector was calculated to be 120 lb/hr. This measurement suffers from the same difficulties as the measurement of the boiler hopper reinjection rate. The line may also have been partially plugged. As shown in Figure 5-5, if 60% of the mechanically collected flyash were reinjected (design rate), the reinjection rate would be on the order of 1084 lb/hr, or twelve times the measured rate.

These measurements did not produce results which would allow for a good ash balance. A good ash balance would include measuring the ash flows from all reinjection lines simultaneously. Such a test was not included in the scope of work for this program. At Site B, this would have required a level of effort and additional expense which was not justifiable at the time of these tests.

#### 5.2.2 Test 23, Reduced Reinjection

During Test 23, the mechanical dust collector reinjection rate was reduced, and emissions were measured. The reduction was accomplished by extending a pipe from the bottom of each reinjection line into a sealed drum. Reinjection air pressure was reduced to near zero but the lines were not capped off. Therefore, some of the ash was reinjected and some was collected in the drums. In this manner, the reinjection rate was reduced without dismantling the reinjection hardware.

Ash was collected at a rate of 460 lb/hr over a 2-1/2 hour period. This represents 30% of the calculated normal reinjection rate (see Figure 5-5), or a 30% reduction in the reinjection rate from the mechanical dust collector.

Test 25 was run under similar conditions as Test 23 except that flyash reinjection was not reduced. The emissions and efficiency of these two tests are compared in Table 5-2. Test 23 (reduced reinjection) resulted in a 39% lower particulate loading at the boiler outlet and a 19% lower particulate loading at the collector outlet than Test 25, but also resulted in a 2.2%

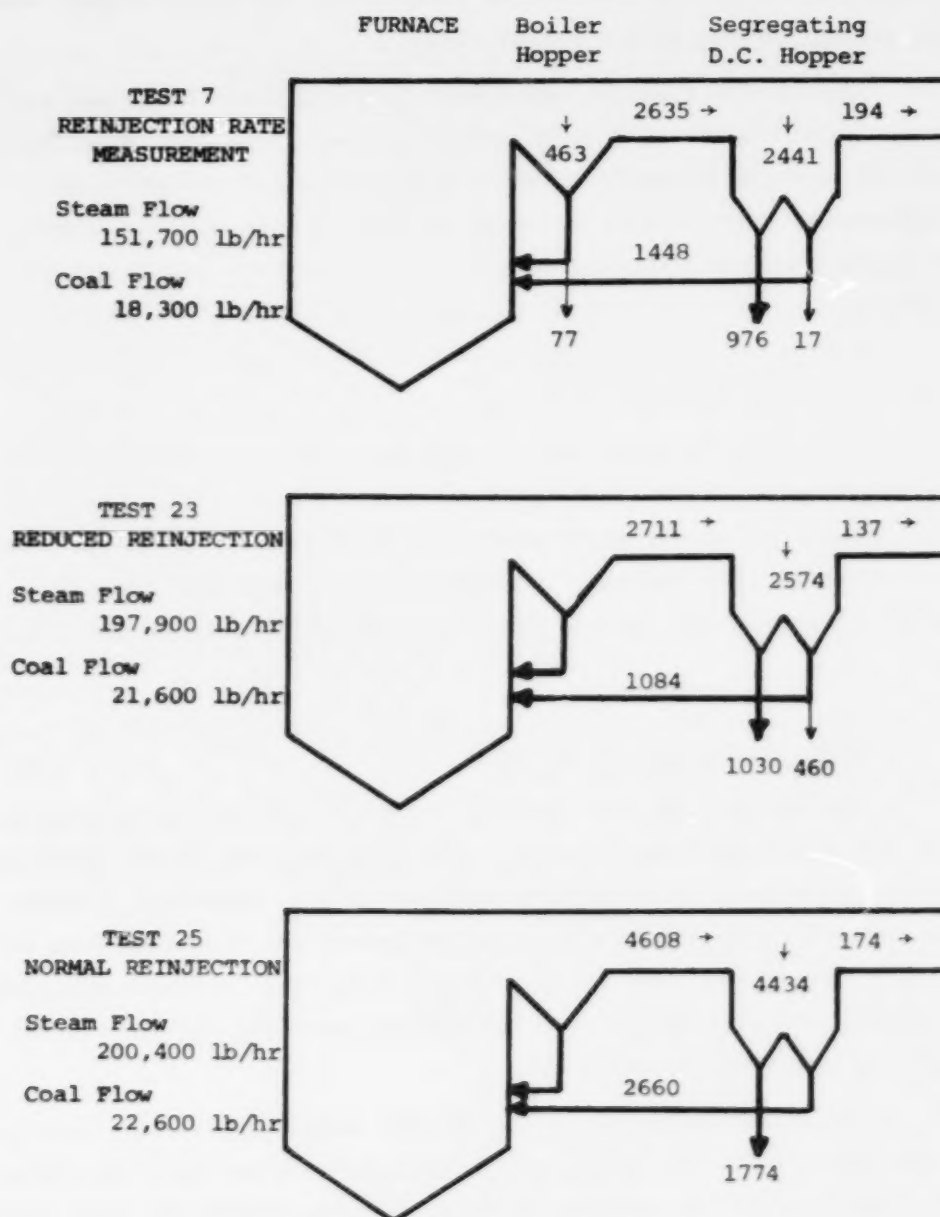


Figure 5-5. Fly ash flow rates for different reinjection configurations, Test Site B. All numbers are mass flow rate in lb/hr.

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TABLE 5-2. EFFECT OF FLY ASH REINJECTION  
ON EMISSIONS AND EFFICIENCY

|                                                    | Test No. 23         | Test No. 25         |
|----------------------------------------------------|---------------------|---------------------|
| Fly Ash Reinjection Rate                           | Reduced 20%         | Normal              |
| <u>FIRING CONDITIONS</u>                           |                     |                     |
| Coal Supplier                                      | Kentucky Cumberland | Kentucky Cumberland |
| Load, % of Capacity                                | 99                  | 100                 |
| Grate Heat Release, $10^3$ BTU/ft <sup>2</sup> /hr | 764                 | 791                 |
| Coal Sizing, % passing 1/4"                        | 36                  | 25                  |
| Excess Air, %                                      | 34                  | 32                  |
| <u>BOILER OUTLET EMISSIONS</u>                     |                     |                     |
| Particulate Loading, lb/10 <sup>6</sup> BTU        | 9.59                | 15.75               |
| Combustible Loading, lb/10 <sup>6</sup> BTU        | 5.84                | 7.40                |
| Inorganic Ash Loading, lb/10 <sup>6</sup> BTU      | 3.75                | 8.35                |
| Combustibles in Fly Ash, %                         | 60.9                | 47.0                |
| O <sub>2</sub> , % (dry)                           | 5.5                 | 5.3                 |
| CO, ppm (dry) @ 3% O <sub>2</sub>                  | 41                  | 60                  |
| NO, ppm (dry) @ 3% O <sub>2</sub>                  | 254                 | 317                 |
| <u>MULTICLONE OUTLET EMISSIONS</u>                 |                     |                     |
| Particulate Loading, lb/10 <sup>6</sup> BTU        | 0.485               | 0.596               |
| Combustible Loading, lb/10 <sup>6</sup> BTU        | 0.129               | 0.149               |
| Inorganic Ash Loading, lb/10 <sup>6</sup> BTU      | 0.356               | 0.447               |
| Combustibles in Fly Ash, %                         | 26.7                | 25.0                |
| Multiclone Collection Efficiency, %                | 94.9                | 96.2                |
| <u>HEAT LOSSES, %</u>                              |                     |                     |
| Dry Gas Loss                                       | 7.96                | 7.66                |
| Moisture in Fuel                                   | 0.52                | 0.27                |
| H <sub>2</sub> O from Combustion of H <sub>2</sub> | 4.42                | 4.21                |
| Combustibles in Collected Fly Ash                  | 8.09                | 6.76                |
| Combustibles in Emitted Fly Ash                    | 0.24                | 0.24                |
| Combustibles in Bottom Ash                         | 1.01                | 0.64                |
| Radiation Loss                                     | 0.38                | 0.38                |
| Unmeasured Losses                                  | 1.50                | 1.50                |
| Total Losses                                       | 23.85               | 21.66               |
| Boiler Efficiency                                  | 76.15               | 78.34               |

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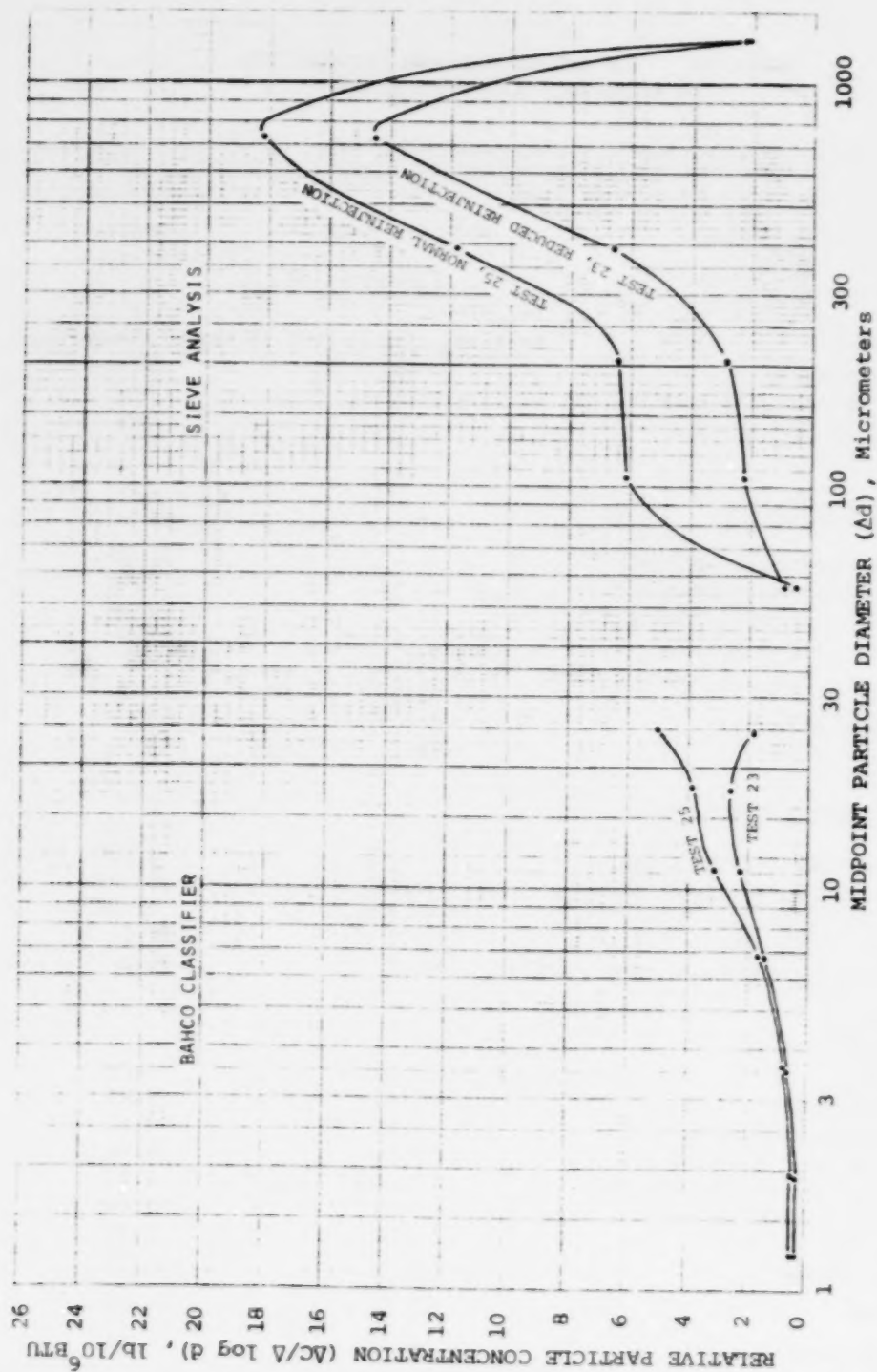


Figure 5-6. Particle size concentrations for boiler outlet particulates under normal and reduced fly ash reinjection conditions - Test Site B.

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lower boiler efficiency. One and one-third percent of this efficiency reduction represents the heating value of the 20% flyash not reinjected. The remaining 0.9% may be due to factors not related to the reduced reinjection.

Particle size concentrations for both tests are shown in Figure 5-6. This data shows that the largest changes in mass concentration occurred above ten micrometers in size.

### 5.3 EXCESS OXYGEN AND GRATE HEAT RELEASE

Boiler B was tested for emissions and efficiency over a full range of loads and excess air conditions. The results of these tests are discussed below. In this discussion, boiler loading is expressed in terms of grate heat release to be more directly relatable to other units.

#### 5.3.1 Excess Oxygen Operating Levels

Excess oxygen operating levels are an important characteristic of a boiler. As excess air is lowered, the dry gas loss (or heat lost out the stack) drops. The lower limit is set by the onset of smoke, excessive CO, or clinking on the grate.

Figure 5-7 shows the oxygen levels at which emissions and efficiency were measured on Boiler B. The shaded area illustrates how the excess air requirement drops as the heat release rate increases. The boundaries shown do not necessarily represent acceptable operating conditions because the tests were of short duration (i.e., 2 to 3 hours). Problems such as clinker and slag formation often require more time to develop.

#### 5.3.2 Particulate Loading vs. Excess Oxygen and Boiler Load

Test data show that particulate loading increases with grate air velocity. The velocity is a function of both excess air and boiler load. This relationship is shown in Figure 5-8.

The variable excess oxygen can be isolated from this data by examining three test sets. Each test set consists of two particulate tests run within 27 hours of each other in which excess oxygen is the only controlled variable. The firing conditions and resulting emissions for these tests are presented in Table 5-3. The data show a significant increase in particulate

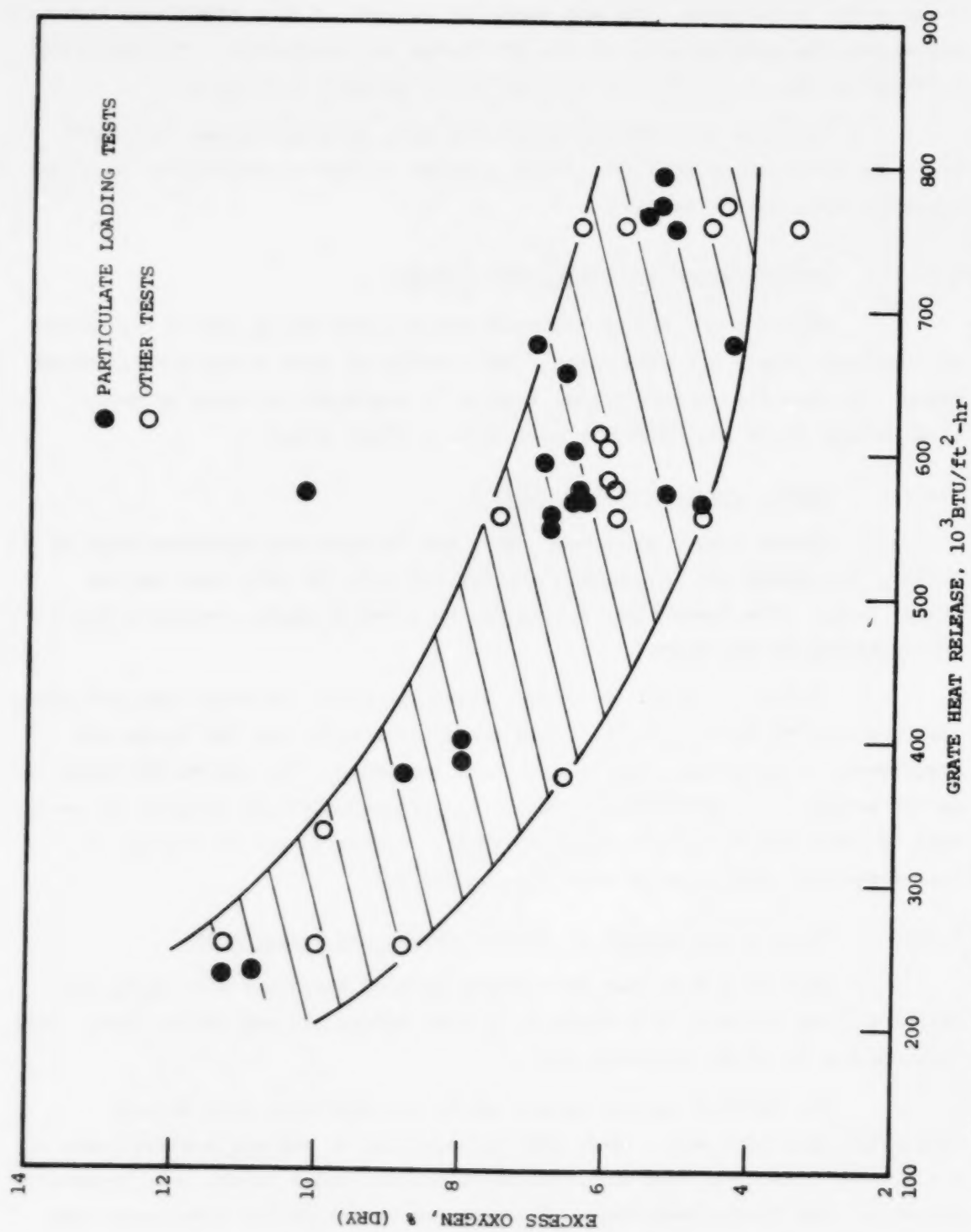


Figure 5-7. Excess oxygen operating levels vs. grate heat release for all tests run at Test Site B. Shaded area represents normal operating range for the stoker.

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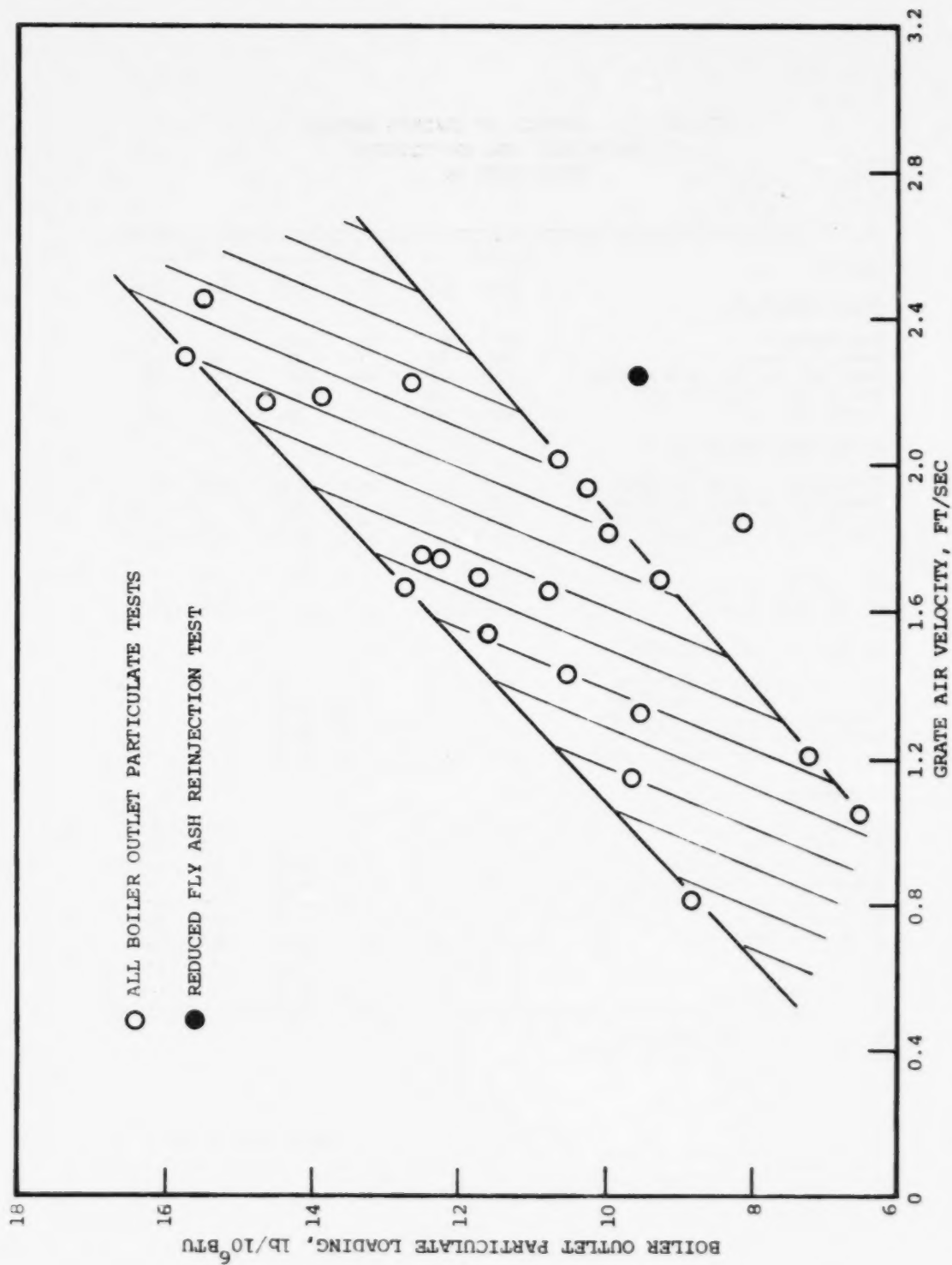


Figure 5-8. Relationship between grate air velocity and particulate loading at Test Site B.

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TABLE 5-3. EFFECT OF EXCESS OXYGEN  
ON EMISSIONS AND EFFICIENCY  
TEST SITE B

| TEST NO.                                                    | Set 1                  |                       | Set 2                  |                       | Set 3                  |                       |
|-------------------------------------------------------------|------------------------|-----------------------|------------------------|-----------------------|------------------------|-----------------------|
|                                                             | High<br>O <sub>2</sub> | Low<br>O <sub>2</sub> | High<br>O <sub>2</sub> | Low<br>O <sub>2</sub> | High<br>O <sub>2</sub> | Low<br>O <sub>2</sub> |
| <u>PIRING CONDITIONS</u>                                    |                        |                       |                        |                       |                        |                       |
| Coal Supplier*                                              | KC                     | KC                    | KC                     | KC                    | R                      | R                     |
| Load, % of Capacity                                         | 75                     | 73                    | 73                     | 75                    | 89                     | 87                    |
| Grate Heat Release, 10 <sup>3</sup> BTU/ft <sup>2</sup> -hr | 571                    | 592                   | 548                    | 564                   | 675                    | 675                   |
| Coal Sizing, % passing 1/4"                                 | 21                     | 28                    | 28                     | 25                    | 35                     | 29                    |
| Excess Air, %                                               | 89                     | 46                    | 46                     | 28                    | 47                     | 25                    |
| <u>BOILER OUTLET EMISSIONS</u>                              |                        |                       |                        |                       |                        |                       |
| Particulate Loading, lb/10 <sup>6</sup> BTU                 | 15.5                   | 8.2                   | 10.8                   | 10.5                  | 14.6                   | 12.5                  |
| Combustible Loading, lb/10 <sup>6</sup> BTU                 | 9.3                    | 5.0                   | 7.0                    | 6.3                   | 11.0                   | 8.6                   |
| Inorganic Ash Loading, lb/10 <sup>6</sup> BTU               | 6.3                    | 3.1                   | 3.8                    | 4.2                   | 3.7                    | 3.9                   |
| Combustibles in Fly Ash, %                                  | 59.7                   | 61.6                  | 65.1                   | 62.0                  | 74.9                   | 69.0                  |
| O <sub>2</sub> , % (dry)                                    | 10.2                   | 6.9                   | 6.8                    | 4.7                   | 7.0                    | 4.3                   |
| CO, ppm (dry) @ 3% O <sub>2</sub>                           | 25.0                   | 120.0                 | 35.0                   | 35.0                  | 48.0                   | 27.0                  |
| NO, ppm (dry) @ 3% O <sub>2</sub>                           | 306.0                  | 237.0                 | 332.0                  | 239.0                 | 294.0                  | 215.0                 |
| <u>MULTICLONE OUTLET EMISSIONS</u>                          |                        |                       |                        |                       |                        |                       |
| Particulate Loading, lb/10 <sup>6</sup> BTU                 | 0.83                   | 0.52                  | 0.56                   | 0.56                  | 0.023                  | 0.018                 |
| Combustible Loading, lb/10 <sup>6</sup> BTU                 | 0.13                   | 0.11                  | 0.16                   | 0.16                  | --                     | --                    |
| Inorganic Ash Loading, lb/10 <sup>6</sup> BTU               | 0.70                   | 0.40                  | 0.40                   | 0.40                  | --                     | --                    |
| Combustibles in Fly Ash, %                                  | 15.40                  | 21.90                 | 28.00                  | 28.80                 | --                     | --                    |
| Multiclone Collection Efficiency, %                         | 94.60                  | 93.70                 | 94.80                  | 94.70                 | --                     | --                    |
| <u>HEAT LOSSES, %</u>                                       |                        |                       |                        |                       |                        |                       |
| Dry Gas Loss                                                | 12.00                  | 8.32                  | 8.26                   | 7.93                  | 8.34                   | 6.53                  |
| Moisture in Fuel                                            | 0.40                   | 0.45                  | 0.46                   | 0.32                  | 0.61                   | 0.50                  |
| H <sub>2</sub> O from Combustion of H <sub>2</sub>          | 4.11                   | 4.23                  | 4.41                   | 4.20                  | 4.15                   | 4.14                  |
| Combustibles in Collected Fly Ash                           | 3.04                   | 2.85                  | 6.53                   | 5.38                  | --                     | --                    |
| Combustibles in Emitted Fly Ash                             | 0.19                   | 0.17                  | 0.27                   | 0.28                  | --                     | --                    |
| Radiation Loss                                              | 0.50                   | 0.52                  | 0.51                   | 0.49                  | 0.42                   | 0.43                  |
| Unmeasured Losses                                           | 1.50                   | 1.50                  | 1.50                   | 1.50                  | 1.50                   | 1.50                  |
| Total Losses                                                | 22.38                  | 19.11                 | 22.38                  | 20.64                 | --                     | --                    |
| Boiler Efficiency                                           | 77.62                  | 80.89                 | 77.61                  | 79.36                 | --                     | --                    |

\*KC - Kentucky Cumberland Coal  
R - Coal reloaded from dead storage

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loading for the first test set but only small increases for sets 2 and 3. The large particulate increase in the first set may be attributable to the fact that the high excess oxygen test (Test No. 8) was well outside the normal operating range at the test load. The normal operating range was defined in Figure 5-7 to be 4.6% to 7.6% O<sub>2</sub> whereas Test 8 was run at 10.2% O<sub>2</sub>. Taking this into consideration, excess oxygen is not, by itself, a very effective control technique for particulate reduction on Boiler B.

Particulate loading at the boiler outlet is plotted against grate heat release in Figure 5-9. Limits are included to define the data trend. At the design grate heat release, particulate loadings range between 12 and 16 lbs of particulate matter per million BTU of coal burned at the boiler outlet.

#### 5.3.3 Carbon Monoxide vs Excess Oxygen and Boiler Load

The carbon monoxide data from all tests is plotted against excess oxygen in Figure 5-10. Carbon monoxide was insignificant at all high load test conditions including the maximum rating on the unit. At low loads, carbon monoxide increased with increasing excess oxygen. The test point at 14% O<sub>2</sub> was an unrealistic firing condition created only for test purposes. Thus, carbon monoxide concentrations remained insignificant throughout the load and excess oxygen operating range of this boiler.

#### 5.3.4 Combustibles vs Excess Oxygen and Boiler Load

Combustibles in the boiler outlet flyash were found to be independent of excess oxygen and slightly dependent on boiler load. The dependency on boiler load is shown in Figure 5-11. In this figure, it appears that combustibles rise slowly with increasing heat release rate and then drop again at peak boiler load. This dependency is so slight as to be statistically insignificant. The average and standard deviation combustible content of the boiler outlet flyash was  $60.3 \pm 7.1\%$ .

Combustibles in the bottom ash are shown plotted against excess oxygen in Figure 5-12. No correlation is evident in the data with either boiler load or excess oxygen. The average and standard deviation of this data is  $12.4 \pm 7.0\%$ . In absolute limits, the combustible content varied from 4.0% to 25.8%.

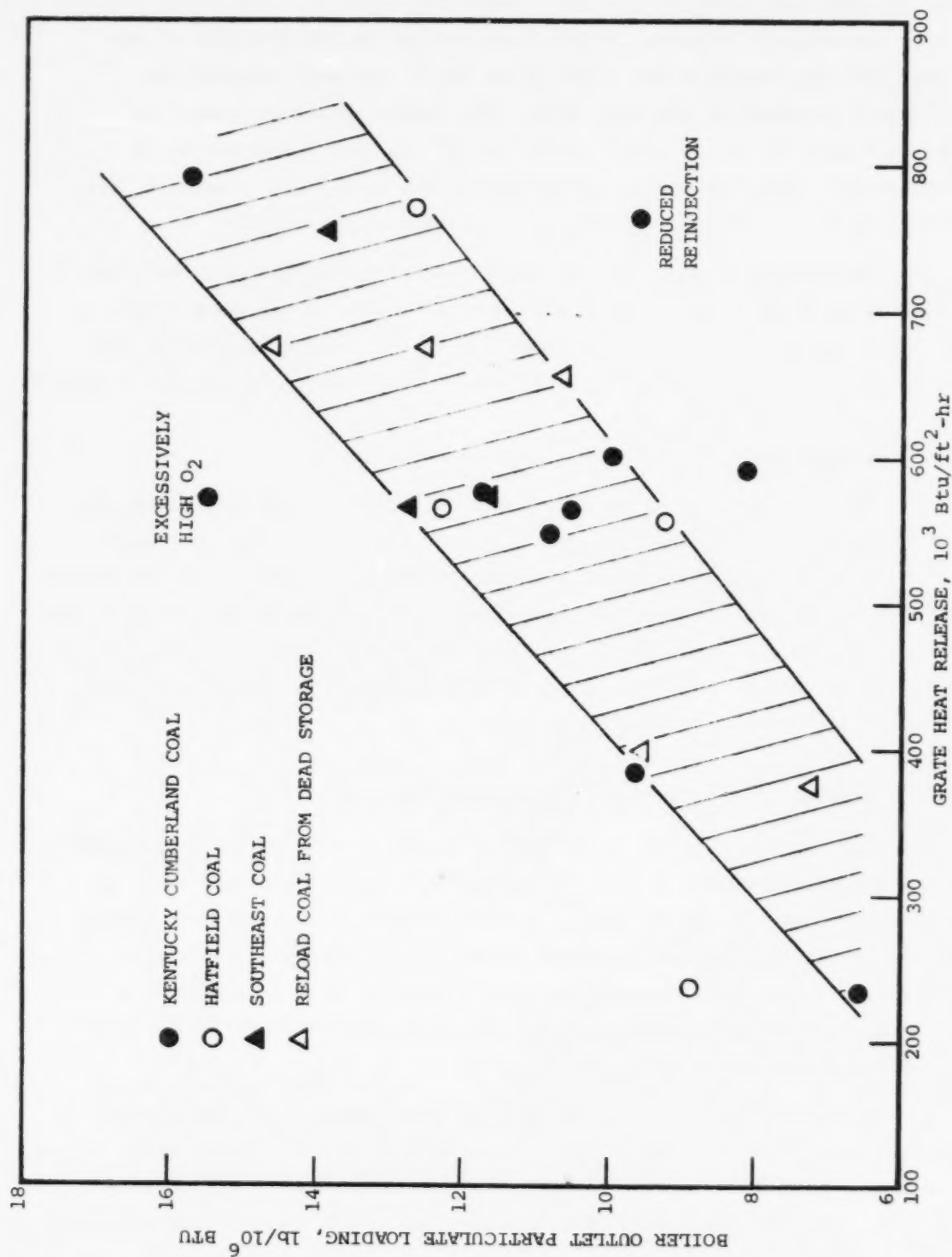


Figure 5-9. Particulate loading at the boiler outlet vs. grate heat release and coal type. Shaded area is shown to emphasize trend - Test Site B.

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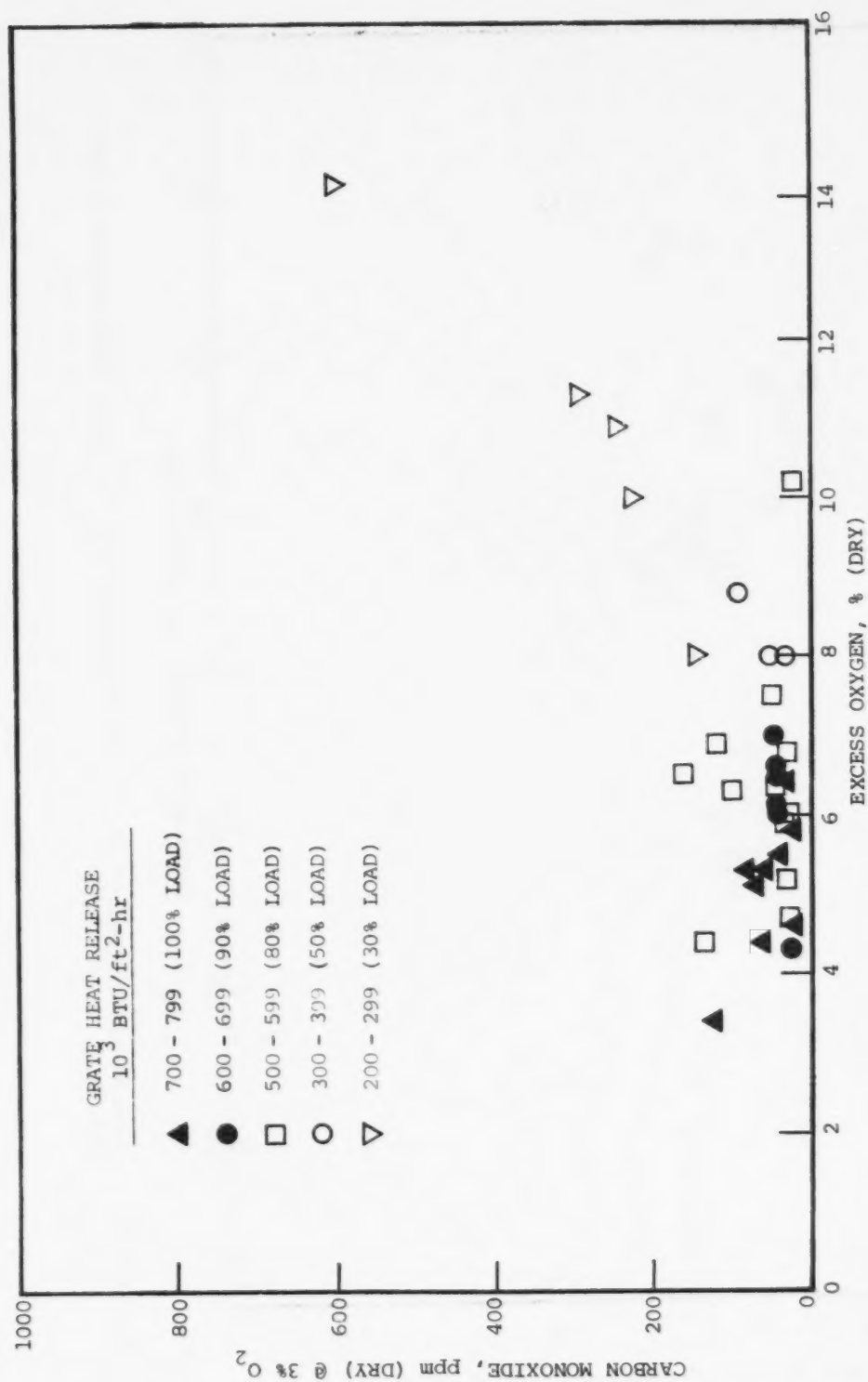


Figure 5-10. Carbon monoxide emissions vs. excess oxygen and grate heat release - Test Site B.

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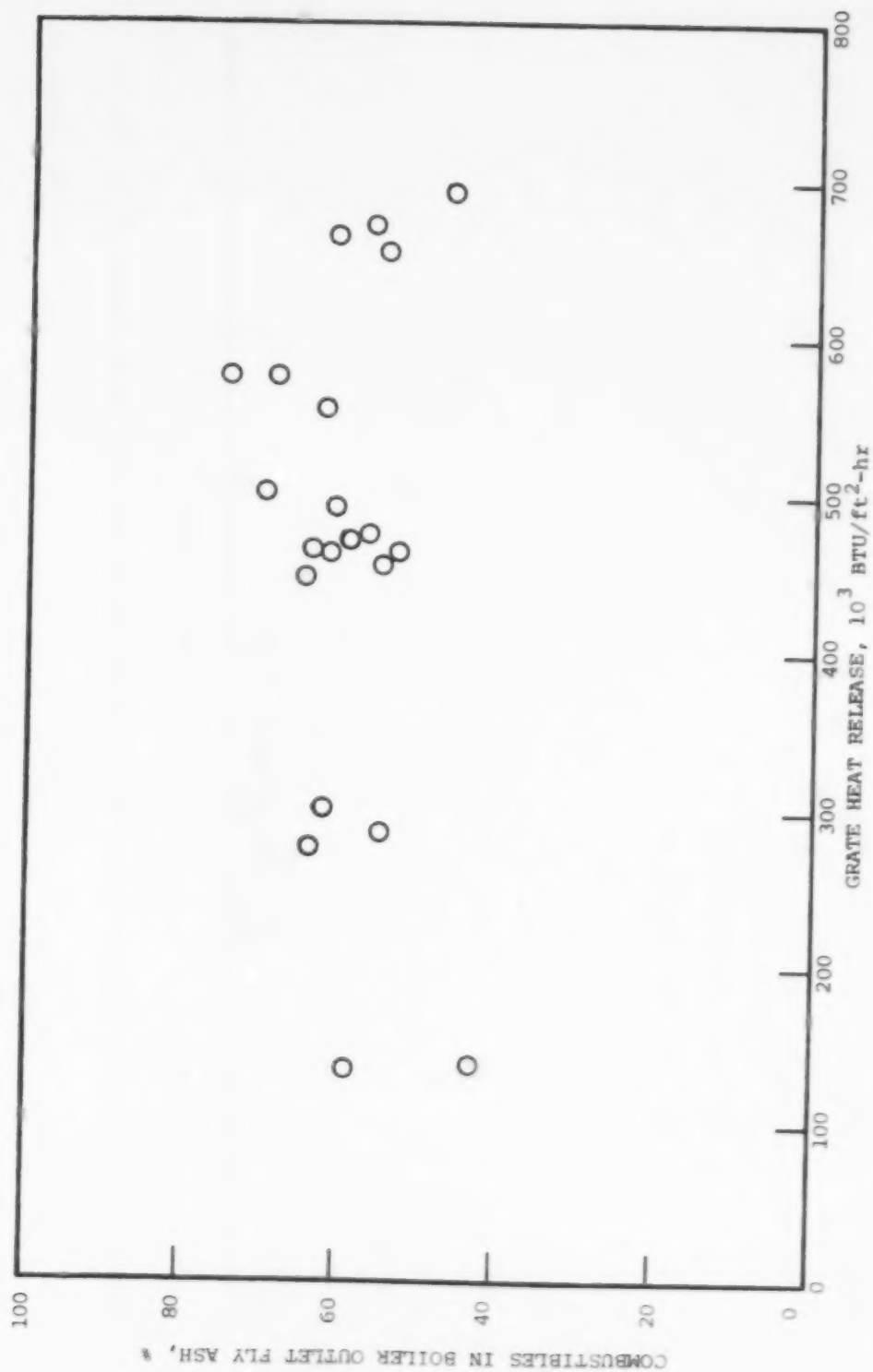


Figure 5-11. Combustible content of the boiler outlet fly ash vs. grate heat release - Test Site B.

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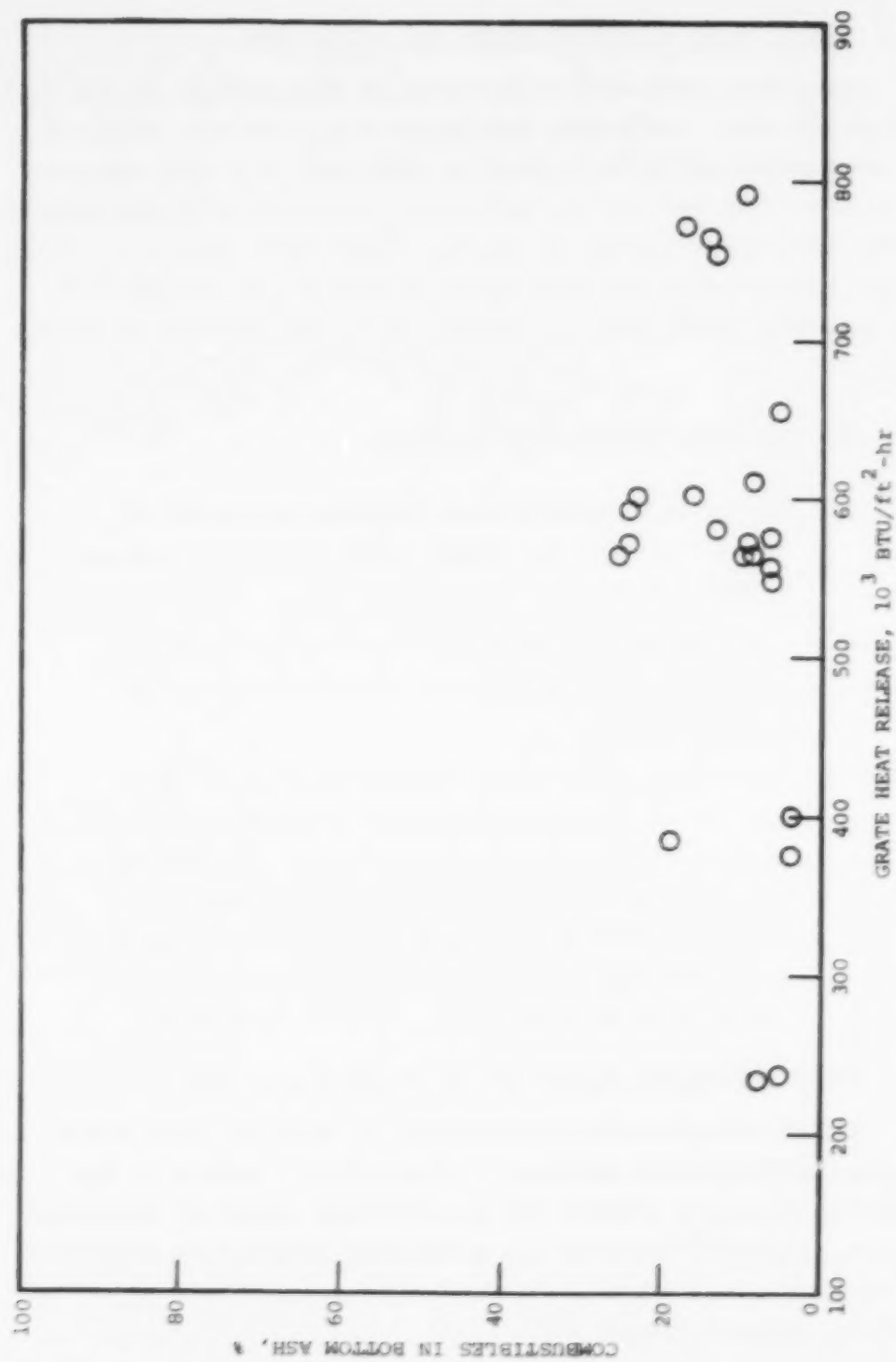


Figure 5-12. Combustible content of the bottom ash vs. grate heat release - Test Site B.

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#### 5.3.5 Nitric Oxide vs. Excess Oxygen and Boiler Load

The nitric oxide data is presented in three graphs. Figure 5-13 presents all the nitric oxide data from Boiler B as a function of excess oxygen. Data points are differentiated by load, and solid lines connect those test sets (Test Nos. 10, 13, and 14) which were designed specifically to find the relationship between NO and O<sub>2</sub>. Figure 5-14 presents the nitric oxide trend lines based on the data points in Figure 5-13. Figure 5-15 presents the nitric oxide data as a function of boiler load for all tests.

The following observations are made:

1. Nitric oxide concentration increases an average of 30 ppm for each one percent increase in O<sub>2</sub> at constant boiler load.
2. Nitric oxide concentration increases an average of 20 ppm for each 10% increase of boiler load at constant excess O<sub>2</sub>.
3. The average nitric oxide concentration is 270 ppm with 90% of all measured data falling within the limits of 227 to 312 ppm at all loads. The counter effects on nitric oxide formation of decreasing excess air with increasing boiler load nearly cancel each other out on this boiler, resulting in a fairly stable emission profile over the full load range.

#### 5.3.6 Boiler Efficiency vs. Excess Oxygen and Boiler Load

Boiler efficiency was calculated by the ASME Heat Loss Method for each test which included measurement of particulate loading at the mechanical dust collector outlet. The measured heat losses are summarized in Table 2-3. Boiler efficiencies are graphically displayed as a function of grate heat release in Figure 5-16; and the dry gas heat loss is plotted against excess oxygen in Figure 5-17.

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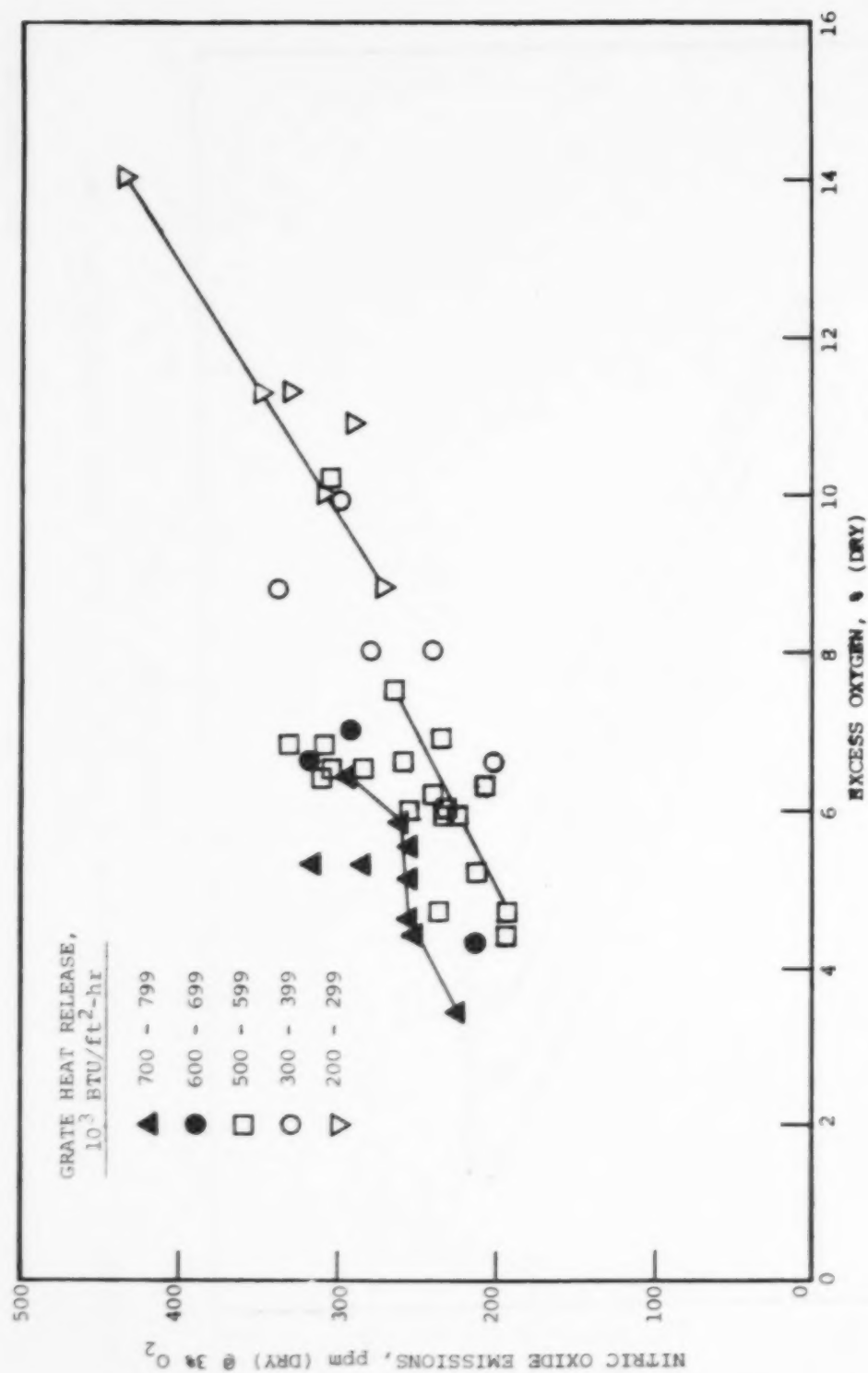


Figure 5-13. Nitric oxide concentration vs. excess oxygen and grate heat release - Test Site B.

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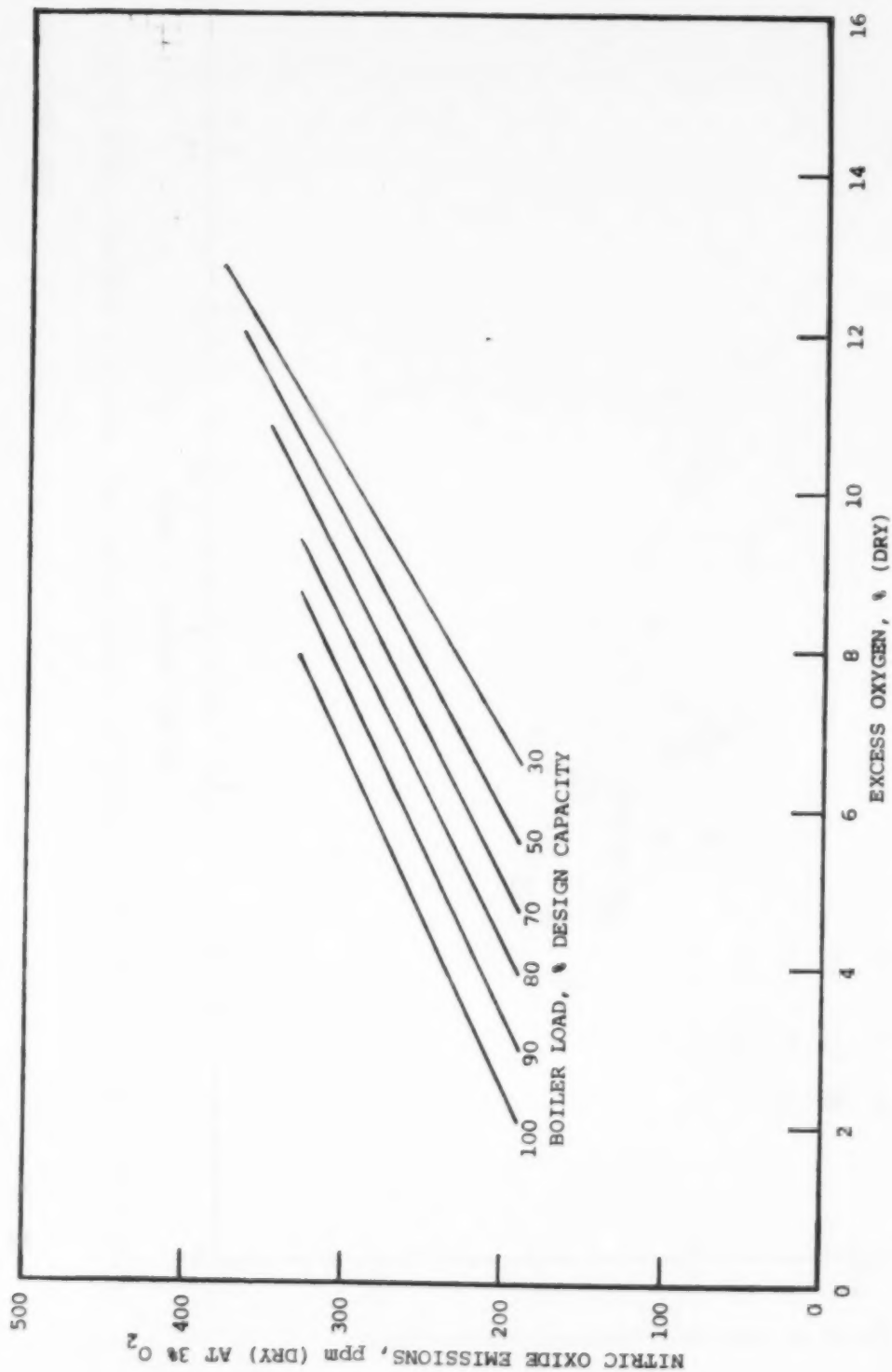


Figure 5-14. Nitric oxide trend lines as a function of excess oxygen and boiler load - Test Site B.

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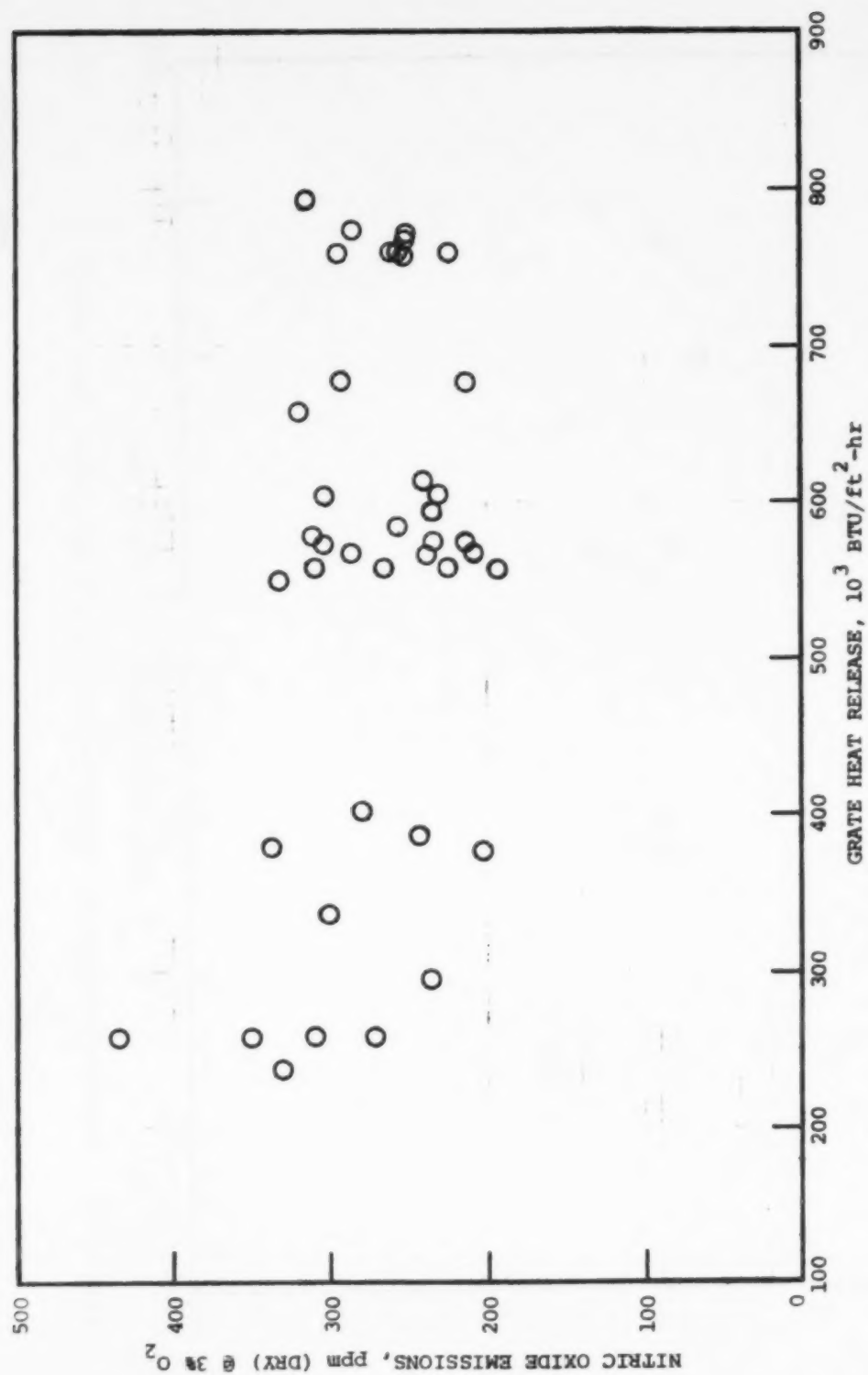


Figure 5-15. Nitric oxide emissions vs. grate heat release for all test conditions - Test Site B.

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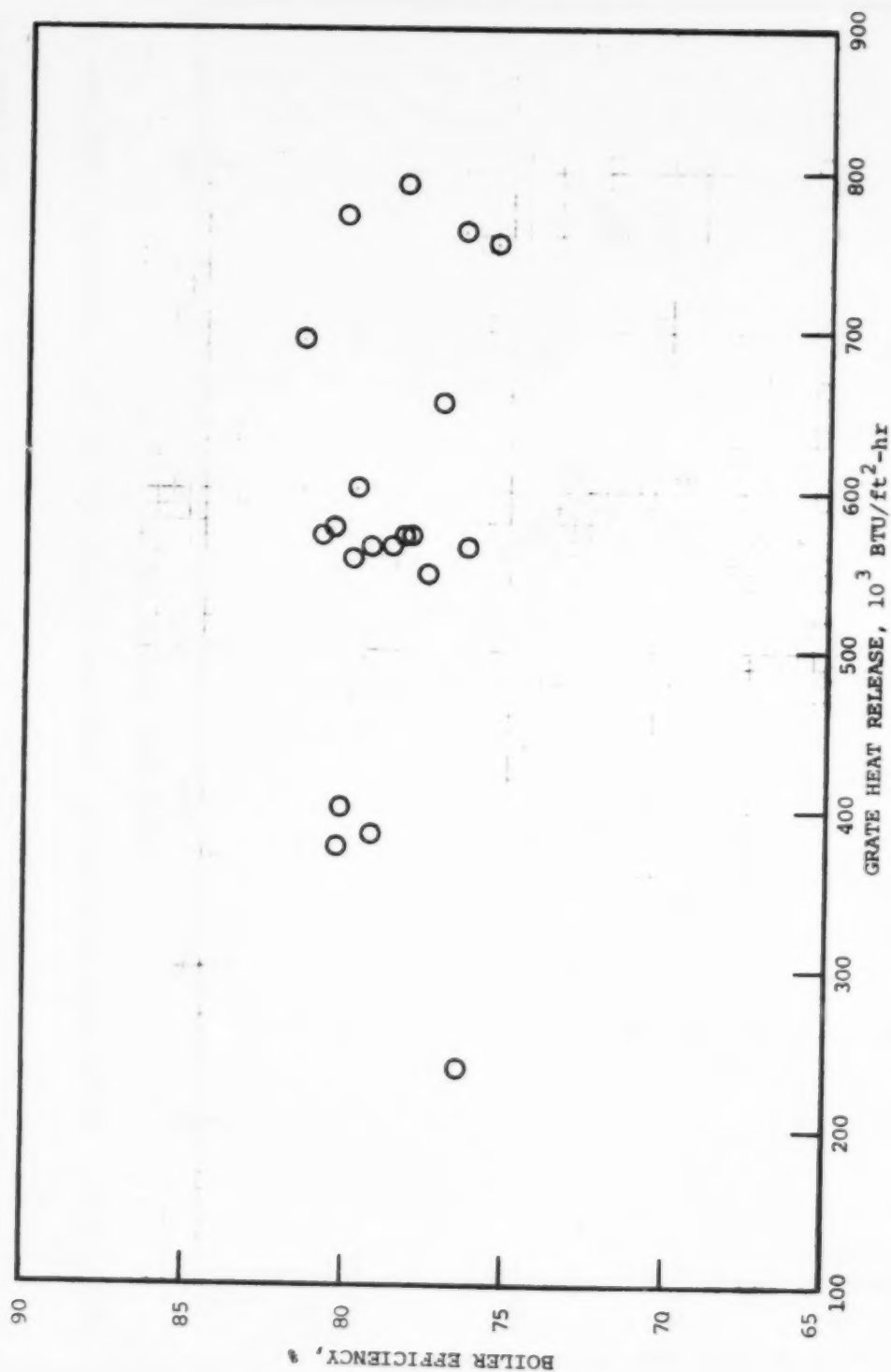


Figure 5-16. Boiler efficiency vs. grate heat release for all tests - Test Site B.

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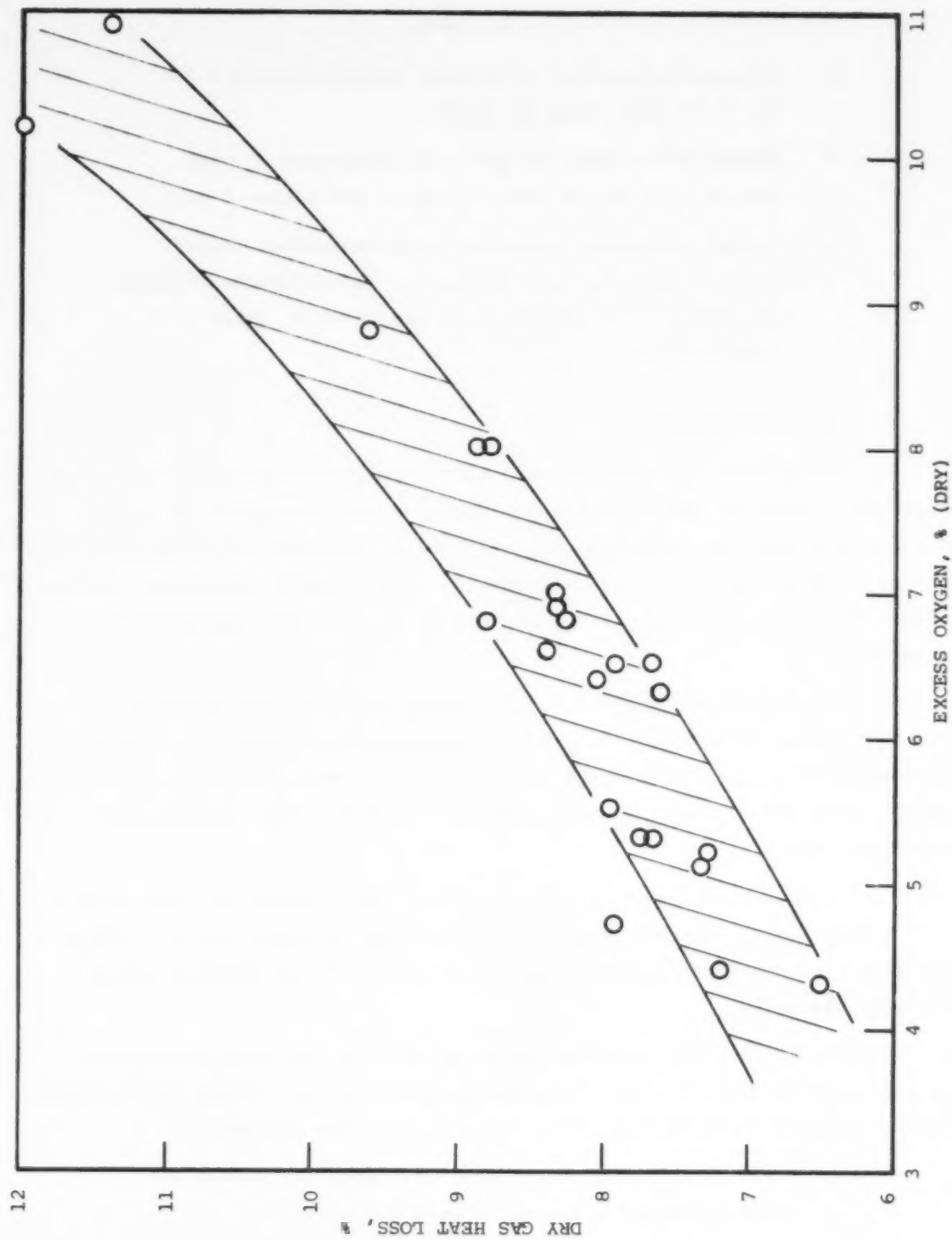


Figure 5-17. Dry gas heat loss vs. excess oxygen for all test conditions - Test Site B.

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The following observations are made:

1. The measured boiler efficiency varied between a low of 75.5% and a high of 80.9%.
2. Boiler efficiency did not vary significantly with boiler load (grate heat release); see Figure 5-16.
3. Boiler efficiency increased with decreasing excess air. A one percent reduction in excess oxygen resulted in about a 0.6% reduction in dry gas heat loss; see Figure 5-17.

#### 5.4 COAL PROPERTIES

Coals from four sources were test fired in Boiler B. These coals varied very little in their properties, and as a result, boiler emissions and efficiency were not significantly affected by the coal selection. Particulate loading, particle size distribution, nitric oxide emissions, carbon monoxide emissions, and combustible content of the ash were unchanged by coal selection.

The "as-fired" proximate analysis of the four test coals are given in Tables 5-14 through 5-17, and are summarized in Table 3-2. Table 5-12 "Summary of Percent Combustibles in Refuse" and Table 5-13 "Coal Sizing Summary" group data by coal type and further illustrate the similarities in the test coals.

Coal size consistency was an uncontrolled variable at Test Site B. It is believed to have an impact on particulate emission levels. Therefore, coal size consistency was measured for each test and examined along with other variables.

The average and standard deviation of each coal's size consistency are compared with the ABMA recommended limits of coal sizing for spreader stokers in Figures 5-18 through 5-21. Two observations are made:

1. Each of the four test coals lies generally within the ABMA recommended limits of coal sizing.

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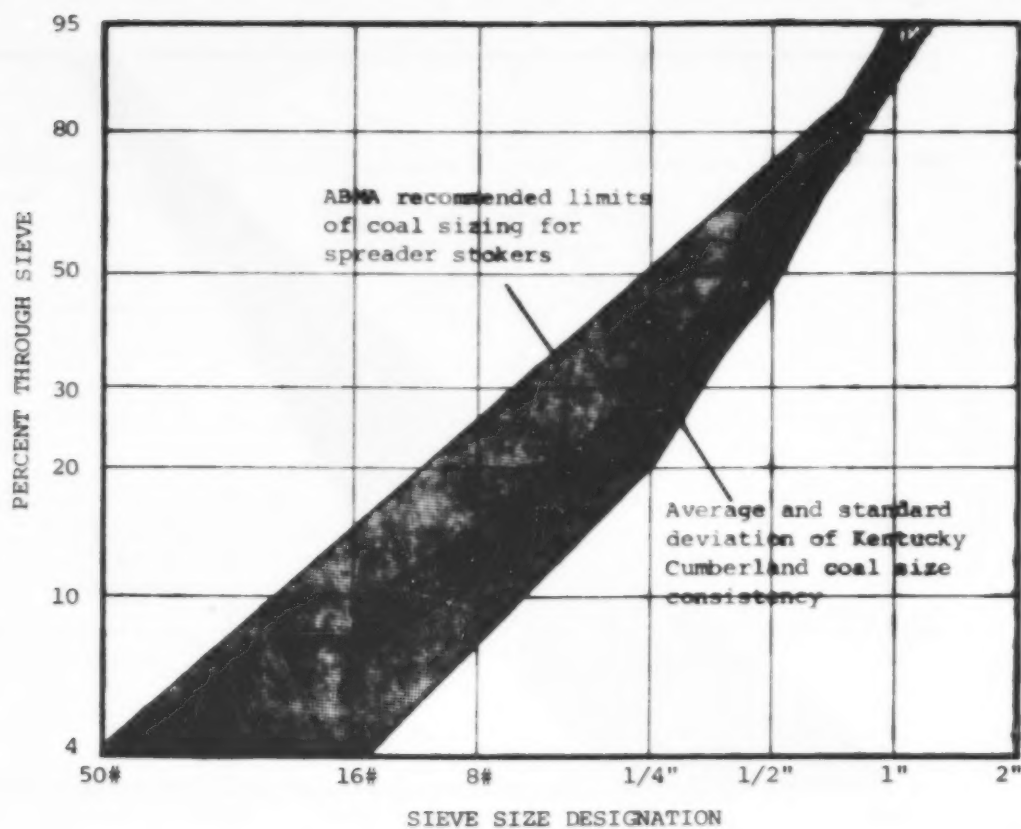


Figure 5-18. Size consistency of "as-fired" Kentucky Cumberland coal vs. ABMA recommended limits of coal sizing for spreader stokers - Test Site B.

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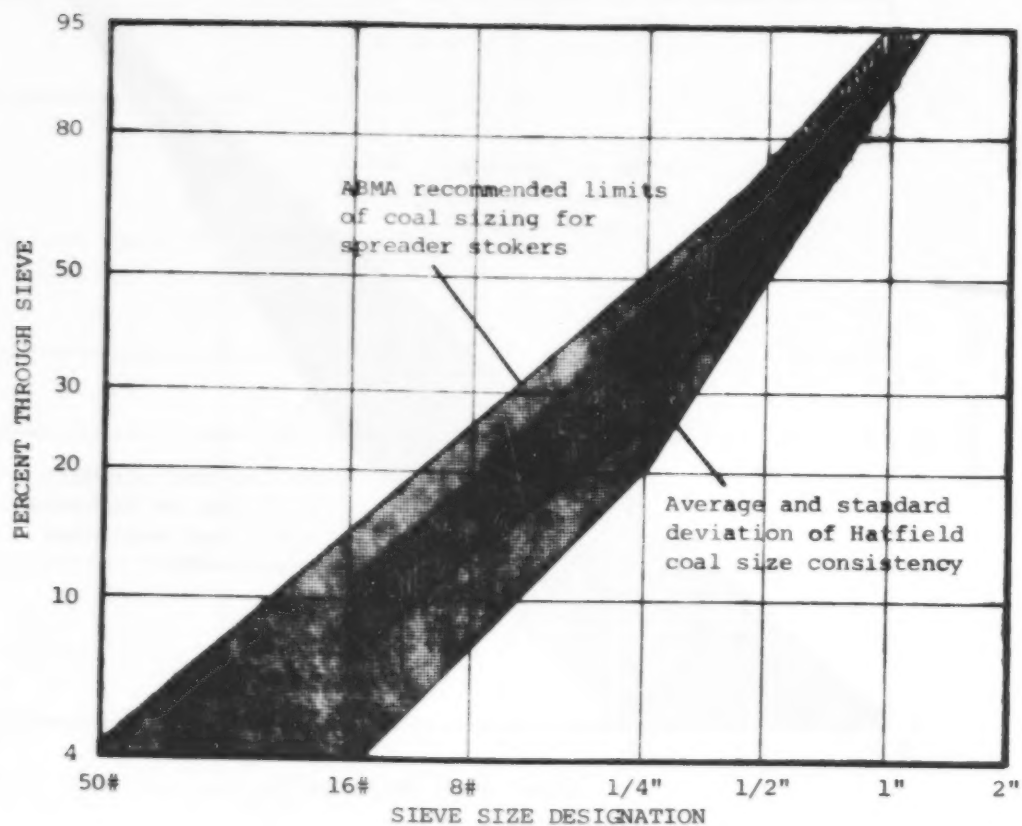


Figure 5-19. Size consistency of "as-fired" Hatfield coal vs. ABMA recommended limits of coal sizing for spreader stokers - Test Site B.

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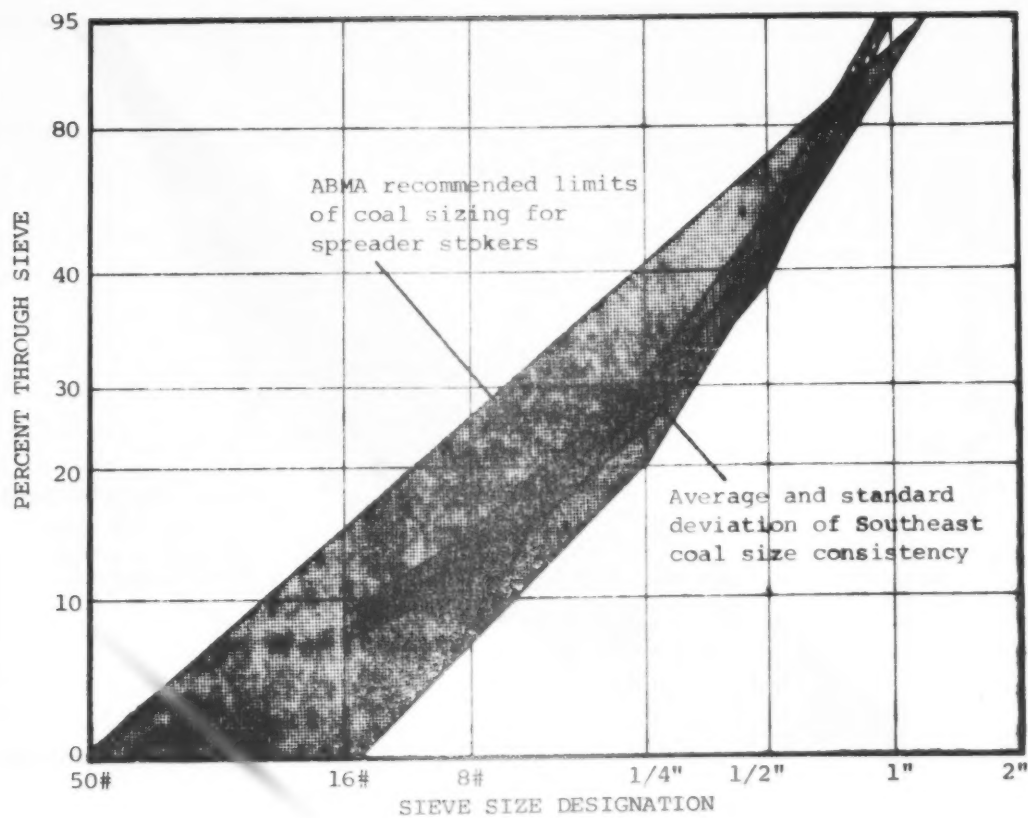


Figure 5-20. Size consistency of "as-fired" Southeast coal vs. ABMA recommended limits of coal sizing for spreader stokers - Test Site B.

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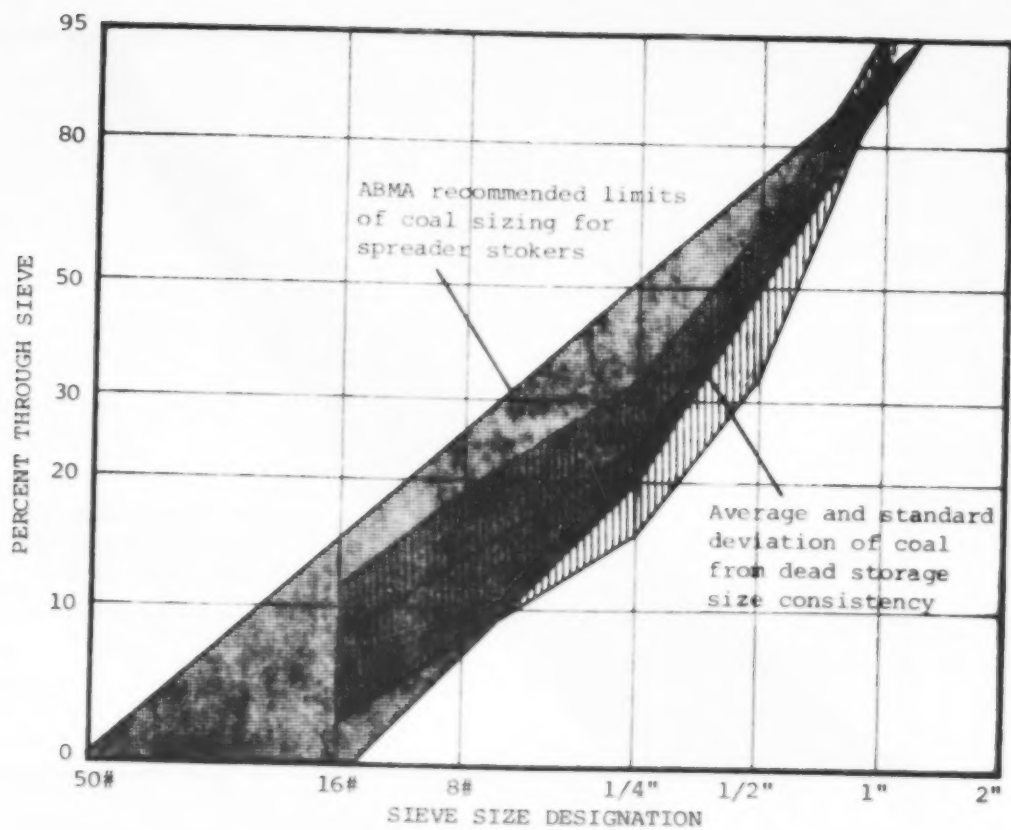


Figure 5-21. Size consistency of "as-fired" coal from dead storage vs. ABMA recommended limits of coal sizing for spreader stokers - Test Site B.

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2. The four test coals are very similar in size consistency.

The fact that the four coals were very similar in size consistency was helpful because it eliminated one uncontrolled variable during testing. The small natural variations in sizing did not noticeably affect emissions. The only operational problem posed by these coals occurred when they were wet and the fines piled in front of the feeders instead of burning in suspension.

#### 5.5 PARTICLE SIZE DISTRIBUTION

A total of 21 particle size distribution tests were run at Test Site B. Both in-situ and laboratory methodology were used. The tests run and methodology used are shown in Table 5-4.

A brief description of the three particle sizing methods used is helpful in understanding the data. The descriptions are given in Section 4.5.

The particle size distribution data are plotted on Figures 5-22, 5-23, and 5-24. Each graph represents all the particle sizing data for one particle sizing method. All of the test data are presented in Table 5-5. This table organizes the data by sample location, sample method, boiler load, and coal source. The table presents the three micrometers and ten micrometers cut points (percent of particulate matter below these sizes) for each test.

Evidence of a relationship between particle size distribution and such variables as boiler load, excess oxygen, and coal selection is inconclusive. However, the data should be helpful to the designers of particulate removal equipment. Commentary on several of the relationships examined is given below.

Coal Selection - No relationship was demonstrated between coal selection and particle size distribution. Referring to Table 5-5, at 100% load, the three coals appeared identical on the Bahco analysis. The SASS tests showed a reverse in the trend at 100% and 78% loads. At 100% load, Kentucky Cumberland had the greatest percentage of particulates below 10 micrometers, while at 78% load it had the least percentage.

TABLE 5-4. PARTICLE SIZE DISTRIBUTION TESTS  
AND METHODOLOGY USED - TEST SITE B

| Test<br>No.     | Coal* | Load<br>% | Particle Size Distribution<br>Methodology Used |                      |            |
|-----------------|-------|-----------|------------------------------------------------|----------------------|------------|
|                 |       |           | Boiler Outlet                                  | Multiclone<br>Outlet | ESP Outlet |
| 4               | K     | 47        | Bahco                                          | --                   | --         |
| 5               | H     | 47        | Brink                                          | --                   | --         |
| 6               | S     | 75        | --                                             | SASS                 | --         |
| 7               | S     | 76        | --                                             | SASS                 | --         |
| 15              | R     | 87        | SASS                                           | --                   | SASS       |
| 16              | R     | 89        | SASS                                           | --                   | SASS       |
| 23 <sup>†</sup> | K     | 99        | Bahco                                          | --                   | --         |
| 24              | S     | 99        | Bahco, SASS                                    | Brink                | --         |
| 25              | K     | 100       | Bahco, SASS                                    | Brink                | --         |
| 26              | H     | 99        | Bahco, SASS                                    | Brink                | --         |
| 30              | H     | 78        | SASS                                           | --                   | --         |
| 31              | K     | 77        | SASS                                           | --                   | --         |
| 33              | S     | 79        | SASS                                           | --                   | --         |

\*K - Kentucky Cumberland coal

H - Hatfield coal

S - Southeast coal

R - Reload coal from dead storage

<sup>†</sup> Reduced reinjection test

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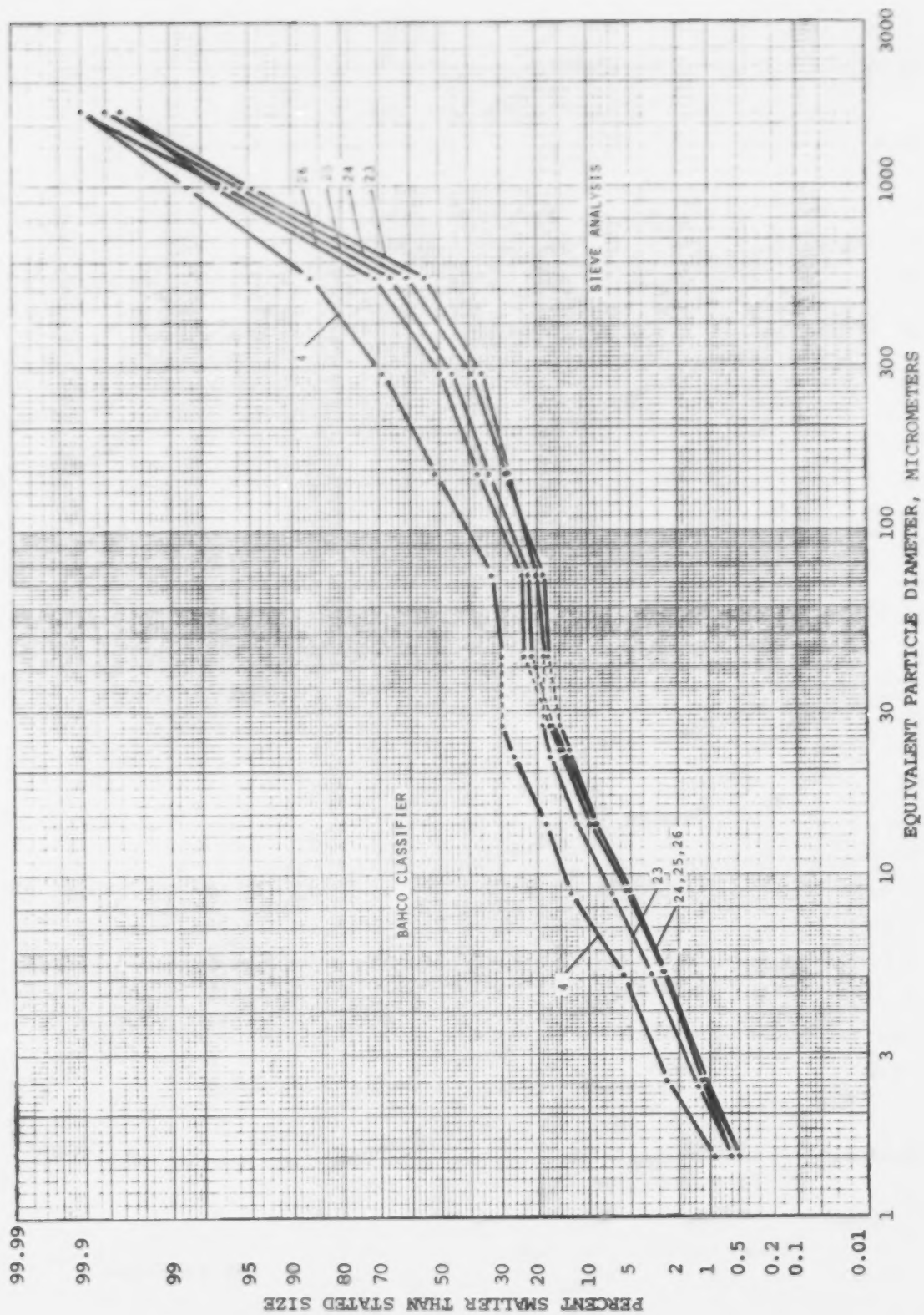


Figure 5-22. Bahco classifier and sieve analysis particle distribution - Test Site B.

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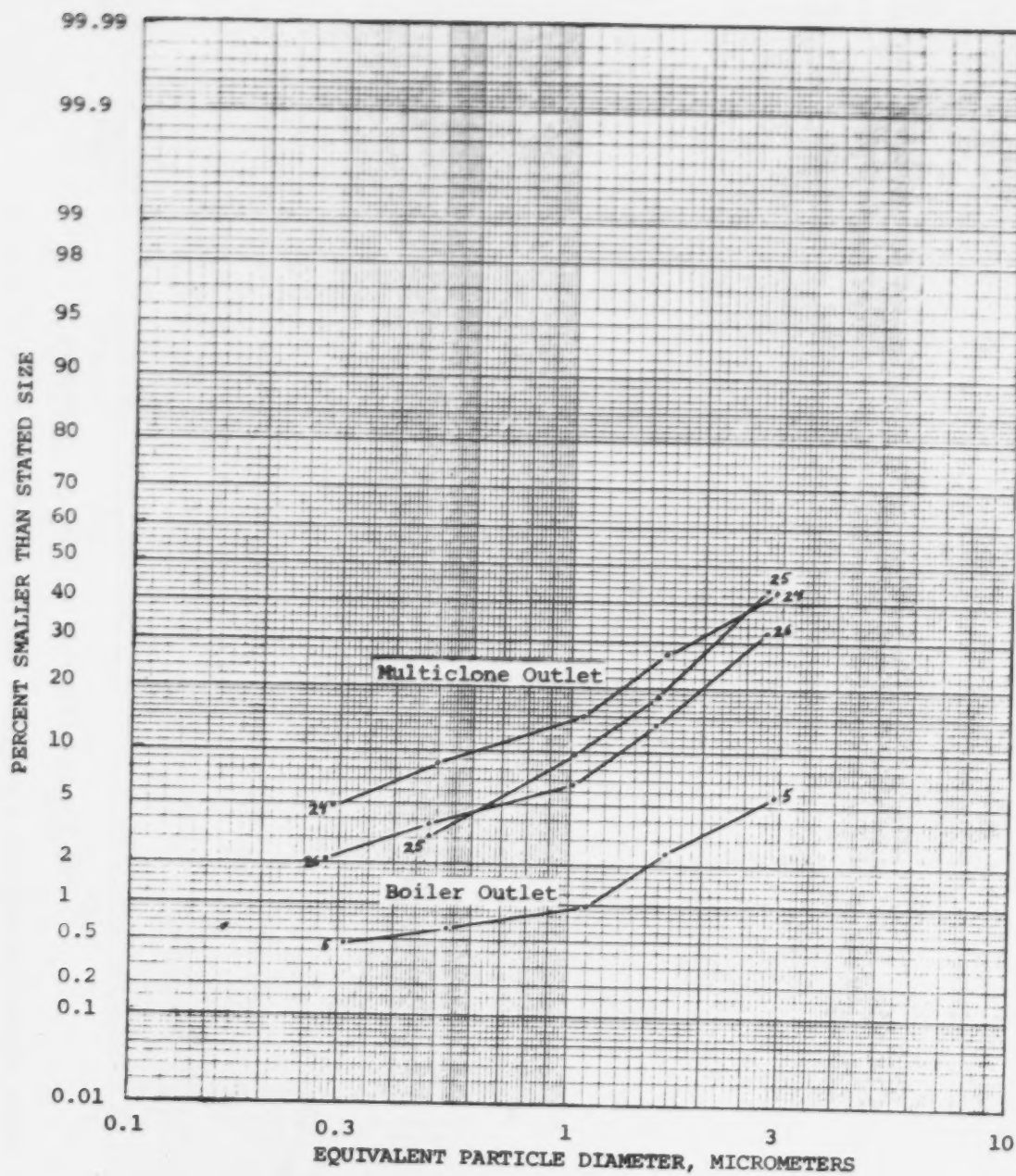


Figure 5-23. Brink cascade impactor particle size distribution, Test Site B.

KVB 15900-524

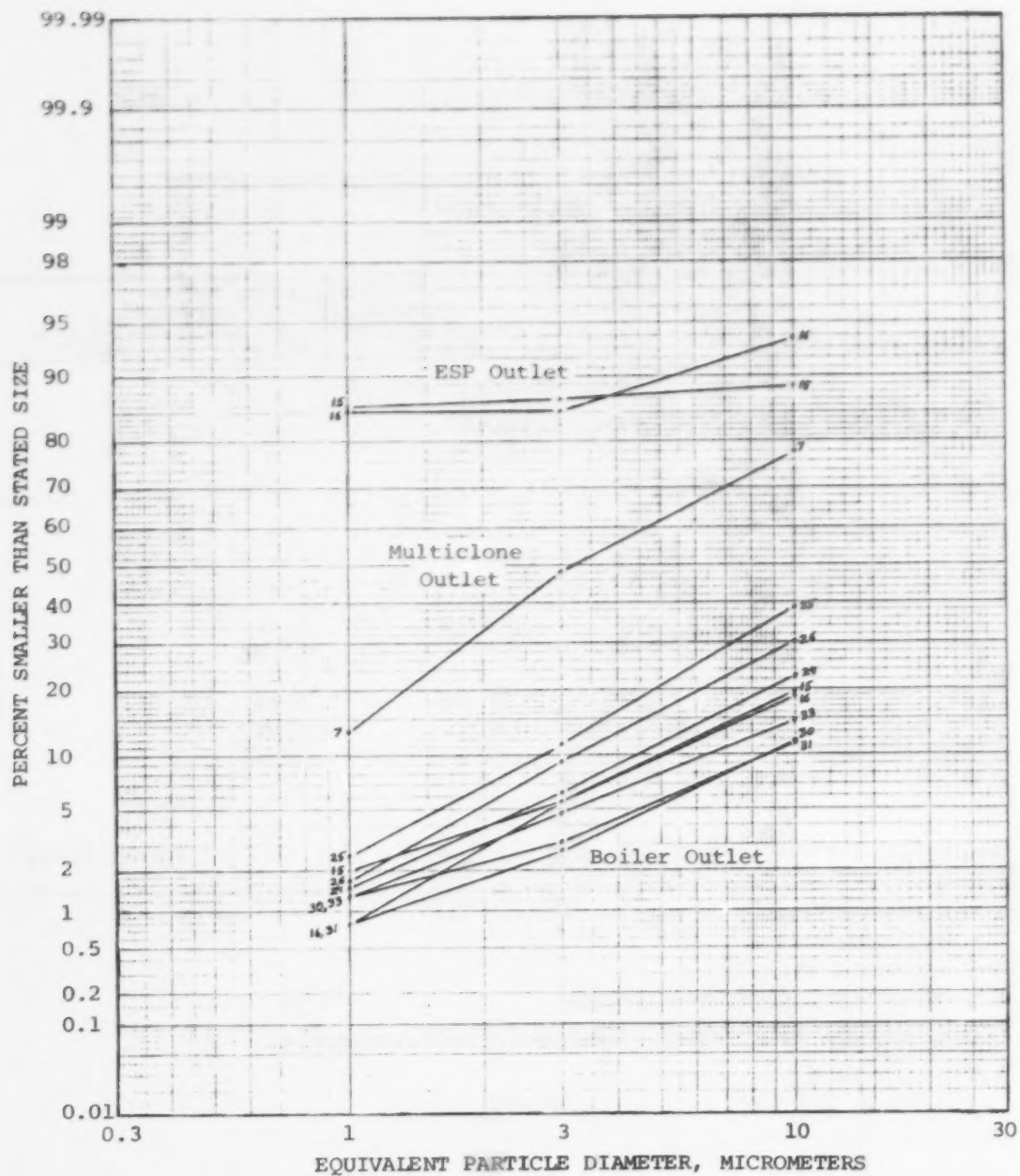


Figure 5-24. SASS gravimetric particle size distribution - Test Site B.

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TABLE 5-5. PARTICLE SIZE DISTRIBUTION TEST RESULTS -  
TEST SITE B

| Sample Location      | Load<br>% | Coal* | % Particulates Below:<br>3 micrometers/10 micrometers |        |                             |
|----------------------|-----------|-------|-------------------------------------------------------|--------|-----------------------------|
|                      |           |       | Bahco                                                 | Brink  | SASS                        |
| Boiler Outlet        | 100       | K     | 1.5/6, 1.8/8 <sup>†</sup>                             | --     | 11.3/39                     |
|                      |           | H     | 1.4/6                                                 | --     | 9.3/30                      |
|                      |           | S     | 1.5/6                                                 | --     | 6.3/23                      |
|                      | 88        | R     | --                                                    | --     | 5.6/20, 5.6/19 <sup>#</sup> |
|                      | 78        | K     | --                                                    | --     | 2.7/12                      |
|                      |           | H     | --                                                    | --     | 3.1/12                      |
|                      |           | S     | --                                                    | --     | 4.8/15                      |
|                      | 47        | K     | 3.2/14                                                | --     | --                          |
|                      |           | H     | --                                                    | 6.2/NA | --                          |
| Multiclone<br>Outlet | 100       | K     | --                                                    | 48/NA  | --                          |
|                      |           | H     | --                                                    | 35/NA  | --                          |
|                      |           | S     | --                                                    | 44/NA  | --                          |
|                      | 78        | S     | --                                                    | --     | 41/78                       |
| ESP Outlet           | 88        | R     | --                                                    | --     | 87/89, 85/94 <sup>#</sup>   |

\*K - Kentucky Cumberland coal

H - Hatfield coal

S - Southeast coal

R - Reload coal from dead storage

<sup>†</sup> Normal fly ash reinjection, reduced fly ash reinjection

<sup>#</sup> 4.3% O<sub>2</sub>, 7.0% O<sub>2</sub>

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Boiler Load - No consistent relationship was demonstrated between boiler load and particle size distribution. In the Bahco tests, the low load evidenced a shift toward smaller particles. In the SASS tests, the reverse was true.

Excess Oxygen - Data is insufficient to draw any conclusions. At 88% load, SASS tests were run at the boiler outlet and at the ESP outlet. At the boiler outlet the sizing results were nearly identical. However, the low O<sub>2</sub> test showed a greater percentage below one micron than the high O<sub>2</sub> test.

Sample Location - Boiler outlet particulates ranged from 1.5% to 11.3% below 3 microns. Multiclone outlet particulates ranged from 35% to 48% below 3 microns. ESP outlet particulates were 85% and 87% below 3 microns.

Sample Method - Bahco tests showed the lowest concentrations of particulates below 10 microns. This is due to the sample portion lost to the EPA Method 5 filter. Brink and SASS tests appear to yield similar results.

Fly Ash Reinjection - The reduced reinjection test showed a shift in particle size to the smaller particles. This shift was small in magnitude.

## 5.6 EFFICIENCY OF POLLUTION CONTROL EQUIPMENT

The emission control equipment of Unit B consisted of a selective type multiclone dust collector and an electrostatic precipitator (ESP). The mechanical dust collector is a UOP Design 104 dynamic centrifugal collector with 140 ten in. collection tubes. Its guaranteed collection efficiency is 90% based on an inlet dust analyzing 10% less than 10 microns. Actual measurements (Table 5-6) showed the collector efficiency to range from 92.7% to 96.6% with an average efficiency of 94.6%. Inlet dust analysis during these tests was 6% less than 10 microns based on Bahco analysis, and 12% to 39% less than 10 microns based on SASS gravimetric data. Thus, the mechanical DC performance was found to be well within guaranteed limits.

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TABLE 5-6. EFFICIENCY OF POLLUTION CONTROL EQUIPMENT

| Test No. | Load % | O <sub>2</sub> % | Equipment        | Particulate Loading<br>lb/10 <sup>6</sup> BTU |        | Efficiency % | Remarks                       |
|----------|--------|------------------|------------------|-----------------------------------------------|--------|--------------|-------------------------------|
|          |        |                  |                  | Inlet                                         | Outlet |              |                               |
| 3        | 27     | 10.9             | Multiclone D.C.  | 10.32                                         | 0.543  | 94.7         |                               |
| 4        | 47     | 8.0              | "                | 9.65                                          | 0.446  | 95.4         |                               |
| 6        | 75     | 5.2              | "                | 11.65                                         | 0.469  | 96.0         | Severe clinkering             |
| 7        | 76     | 4.4              | "                | 10.28                                         | 0.755  | 92.7         | Reduced OFA                   |
| 8        | 75     | 10.2             | "                | 15.51                                         | 0.830  | 94.6         |                               |
| 9        | 73     | 6.9              | "                | 8.16                                          | 0.518  | 93.7         |                               |
| 11       | 48     | 8.8              | "                | 7.21                                          | 0.481  | 93.3         |                               |
| 12       | 49     | 8.0              | "                | 9.57                                          | 0.500  | 94.8         | Reduced OFA                   |
| 15       | 87     | 4.3              | Multiclone & ESP | 12.53                                         | 0.023  | 99.82        |                               |
| 16       | 89     | 7.0              | "                | 14.63                                         | 0.018  | 99.88        |                               |
| 17       | 88     | 6.6              | Multiclone D.C.  | 10.66                                         | 0.467  | 95.6         |                               |
| 18       | 74     | 6.5              | "                | 12.76                                         | 0.810  | 93.7         | Bottom ash pulled during test |
| 19       | 75     | 4.7              | "                | 10.53                                         | 0.563  | 94.7         |                               |
| 20       | 73     | 6.8              | "                | 10.81                                         | 0.561  | 94.8         |                               |
| 21       | 73     | 6.8              | "                | 9.25                                          | 0.619  | 93.3         |                               |
| 22       | 72     | 6.3              | "                | 12.27                                         | 0.824  | 93.3         | Reduced OFA                   |
| 23       | 99     | 5.5              | "                | 9.59                                          | 0.485  | 94.9         | Reduced reinjection           |
| 24       | 99     | 5.1              | "                | 13.88                                         | 3.53   | 74.6         |                               |
| 25       | 100    | 5.3              | "                | 15.75                                         | 0.596  | 96.2         |                               |
| 26       | 99     | 5.3              | "                | 12.67                                         | 0.035  | 95.0         |                               |
| 27       | 79     | 6.4              | "                | 11.75                                         | 0.591  | 95.0         | Reduced OFA                   |
| 28       | 81     | 6.5              | "                | 9.98                                          | 0.343  | 96.6         |                               |

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Efficiency of the ESP was not measured directly. Instead, the combined efficiency of the mechanical DC and the ESP were measured twice. The results, shown on Table 5-6, were 99.82% and 99.88%. If an ESP inlet loading of  $0.50 \text{ lb}/10^6 \text{ BTU}$  is assumed, the ESP efficiencies become 95.4% and 96.4% for the two tests.

The effect of combustion variables on the mechanical D.C. collection efficiency were not significant. As shown in Figure 5-25, the different coals all produced similar efficiencies. Excess air, overfire air, and even inlet velocity had very little discernable effect on the collection efficiency. Scatter in the data cannot be resolved by the known variables.

Figure 5-26 presents the multiclone outlet particulate loading as a function of grate heat release and coal selection. Neither of these variables shows any discernable relationship to particulate loading after the collector. Average loading was  $0.58 \text{ lb}/10^6 \text{ BTU}$ . During three tests out of 19, the loading was above  $0.80 \text{ lb}/10^6 \text{ BTU}$ .

#### 5.7 MODIFIED SMOKE SPOT NUMBER

Smoke spot readings were taken with a Bacharach smoke spot tester at the boiler outlet. The pump was stroked once or twice each time as opposed to the specified ten times required on an oil-fired unit by ASTM D2156-65. The smoke spot results are tabulated in Table 5-7. They are plotted against particulate loading in Figure 5-27, and against combustible loading in Figure 5-28.

The purpose of this exercise was to develop a quick and easy method of estimating either particulate loading or combustible loading from stoker-fired boilers. It is observed in Figures 5-27 and 5-28 that no correlation could be made.

Based on this data, the modified smoke spot technique is not a useful method for estimating particulate or combustible loadings at the boiler outlet of spreader stokers. A primary reason is its inability to collect on filter paper the large particles which contain the majority of the particulate and combustible mass.

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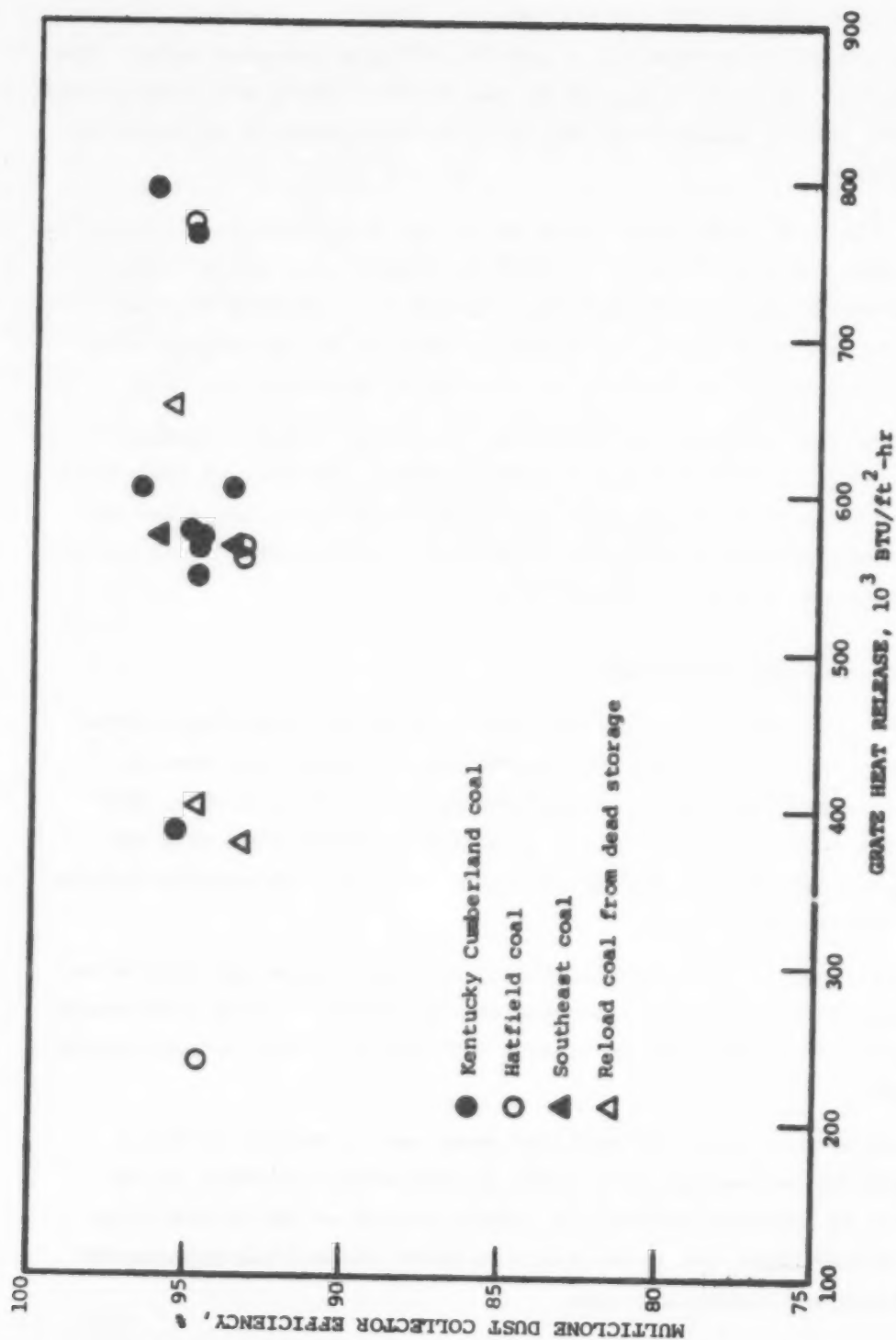


Figure 5-25. Multiclone dust collector efficiency vs. grate heat release and coal selection - Test Site B.

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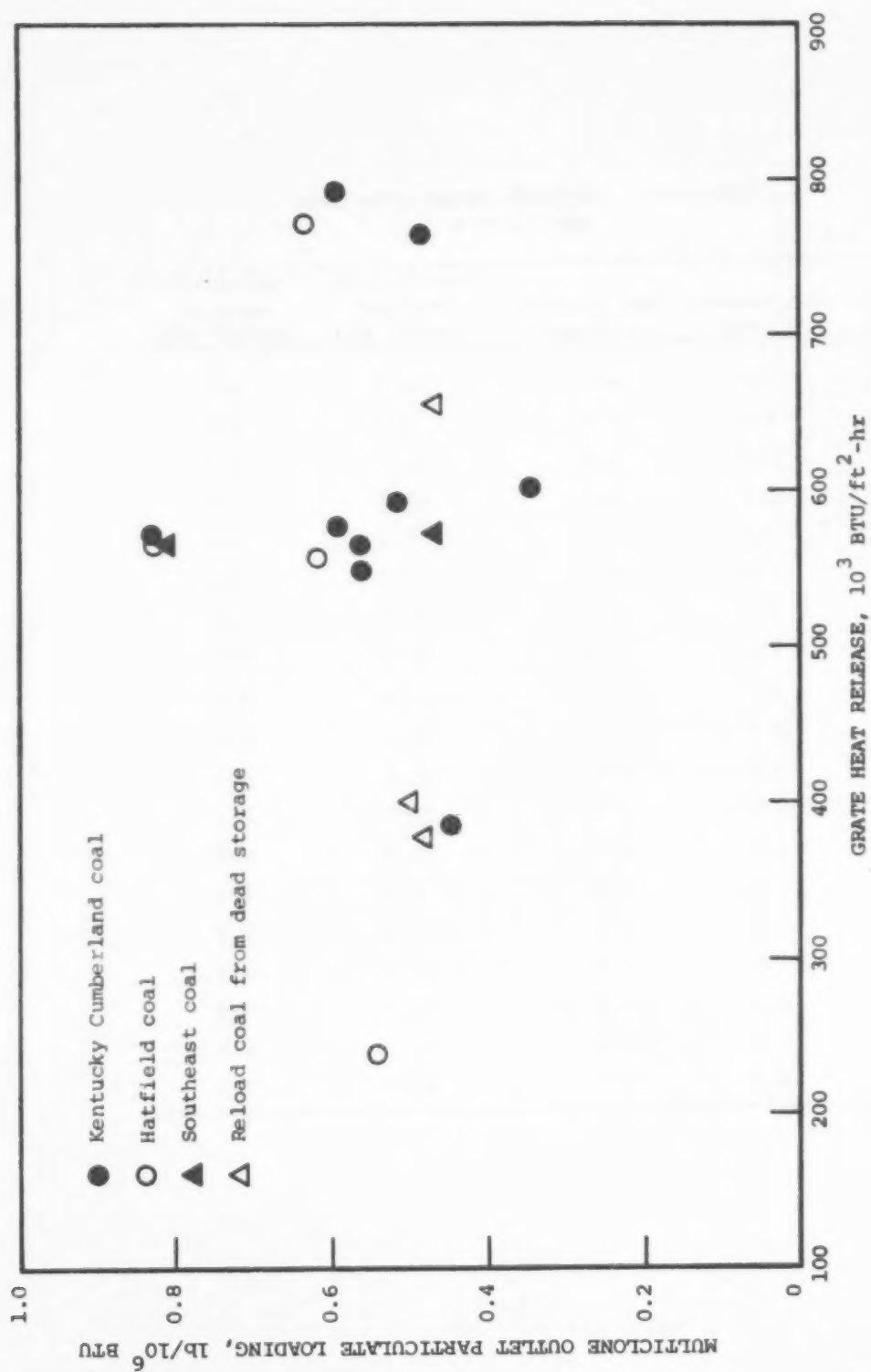


Figure 5-26. Multiclone outlet particulate loading vs. grate heat release and coal selection - Test Site B.

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TABLE 5-7. MODIFIED SMOKE SPOT DATA  
TEST SITE B

| Test No. | Avg Reading<br>1 Pump | Avg Reading<br>2 Pumps | Particulate<br>Loading<br>lb/10 <sup>6</sup> BTU | Combustible<br>Loading<br>lb/10 <sup>6</sup> BTU |
|----------|-----------------------|------------------------|--------------------------------------------------|--------------------------------------------------|
| 3        | 8.0                   | ---                    | 10.3                                             | 4.5                                              |
| 4        | 4.0                   | 6.5                    | 9.7                                              | 5.3                                              |
| 6        | 2.5                   | 3.8                    | 11.7                                             | 4.7                                              |
| 8        | 2.5                   | 3.0                    | 15.5                                             | 5.0                                              |
| 9        | 4.0                   | 5.2                    | 8.2                                              | 4.9                                              |
| 11       | 2.8                   | 4.8                    | 7.2                                              | 4.6                                              |
| 12       | 4.5                   | 6.0                    | 9.6                                              | 6.0                                              |
| 17       | 1.5                   | 3.0                    | 10.7                                             | 6.7                                              |
| 18       | 2.5                   | 4.3                    | 12.8                                             | 8.2                                              |
| 19       | 4.5                   | 6.5                    | 10.5                                             | 6.5                                              |
| 20       | 3.0                   | 4.5                    | 10.8                                             | 7.0                                              |
| 21       | 2.0                   | 3.5                    | 9.2                                              | 5.1                                              |
| 22       | 6.5                   | 8.5                    | 12.3                                             | 6.5                                              |
| 23       | 1.5                   | 2.8                    | 9.6                                              | 5.8                                              |
| 24       | 2.5                   | 4.0                    | 13.9                                             | 7.7                                              |
| 25       | 3.0                   | 5.8                    | 15.8                                             | 7.4                                              |
| 26       | 4.0                   | 5.0                    | 12.8                                             | 7.3                                              |
| 27       | 2.0                   | 3.5                    | 11.7                                             | 6.7                                              |
| 28       | 4.3                   | 4.8                    | 10.0                                             | 7.0                                              |

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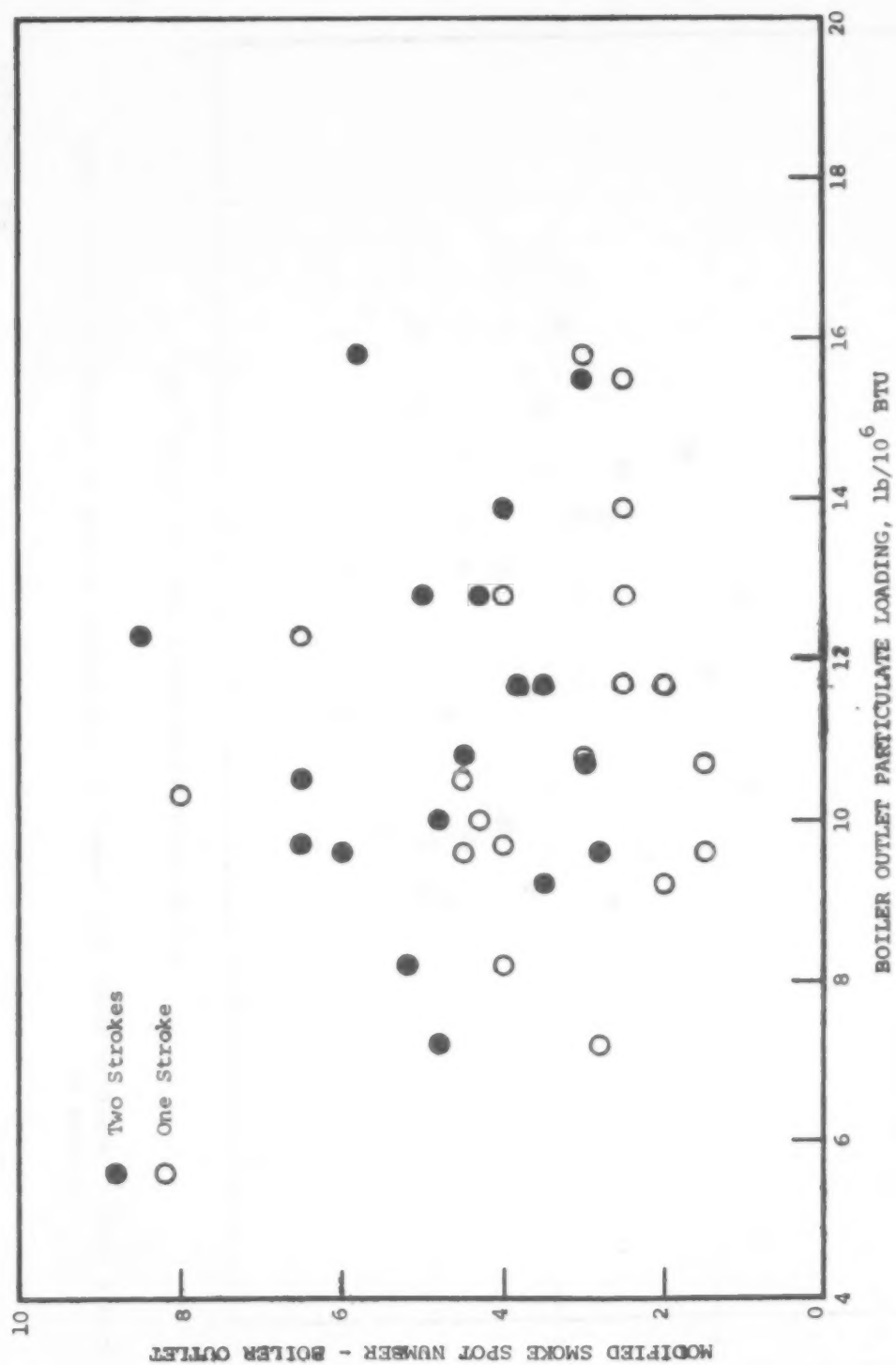


Figure 5-27. Modified smoke spot number vs. particulate loading at the boiler outlet - Test Site B.

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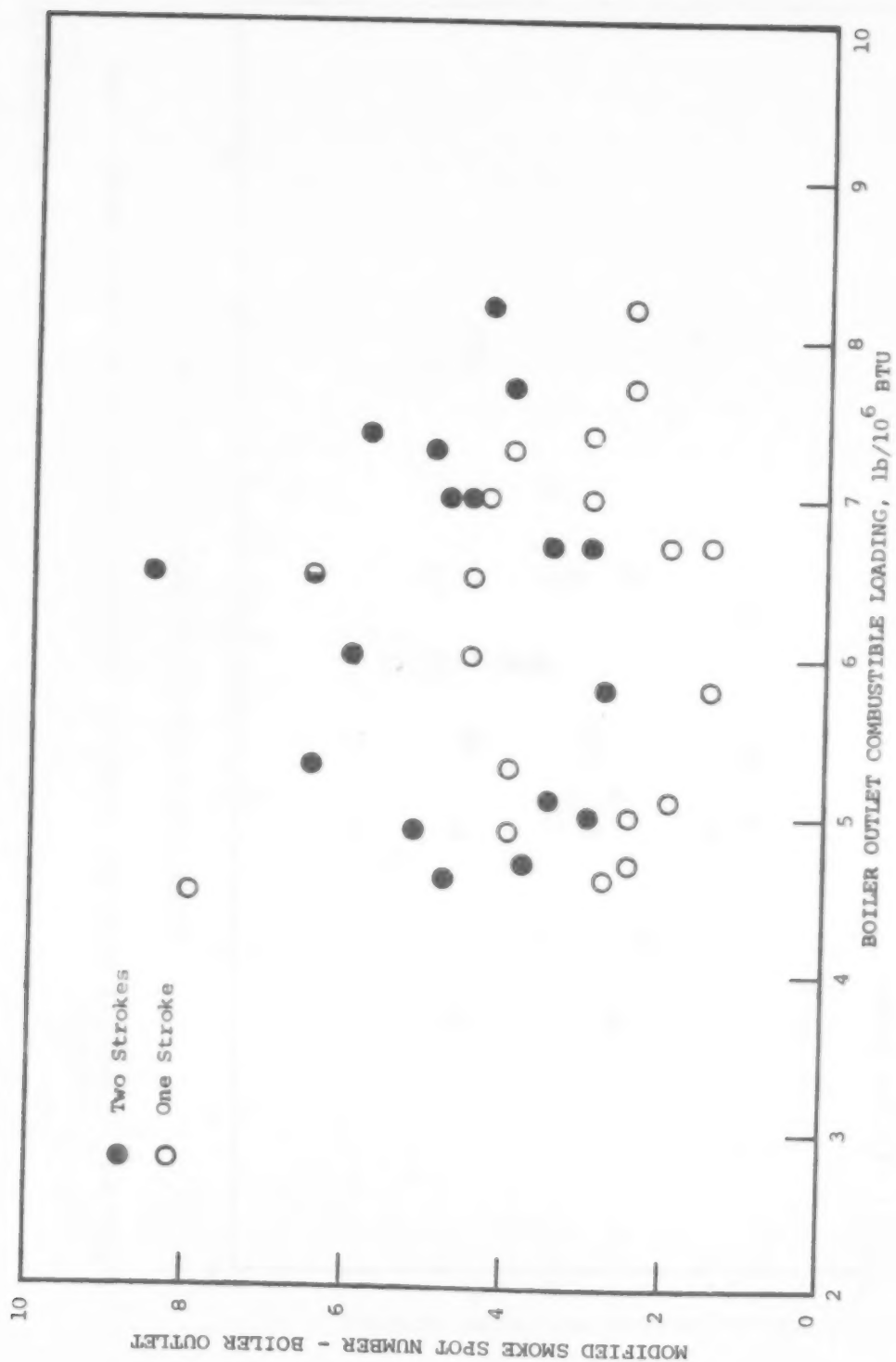


Figure 5-28. Modified smoke spot number vs combustible loading at the boiler outlet - Test Site B.

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## 5.8 SOURCE ASSESSMENT SAMPLING SYSTEM

Seven SASS tests were run at Test Site B. One test was run on each of three main test coals. These tests were run under identical conditions of boiler load, excess O<sub>2</sub>, overfire air, and fly ash reinjection. In addition, two sets of SASS tests were run simultaneously at the boiler outlet and the ESP outlet. These four tests, run on reload coal, were part of a joint test venture with the Aerotherm Division of Acurex Corporation under a separate EPA contract. The conditions under which the seven SASS tests were run are shown in Table 5-8.

TABLE 5-8. SASS TESTS RUN AT SITE B

| Test No. | Sample Location | Coal Origin | Load % | Excess O <sub>2</sub> % | OFA "H <sub>2</sub> O | Contractor for Analysis |
|----------|-----------------|-------------|--------|-------------------------|-----------------------|-------------------------|
| 15A      | Boiler outlet   | Reload      | 87     | 4.3                     | 27                    | Aerotherm               |
| 15B      | ESP outlet      | Reload      | 87     | 4.3                     | 27                    | Aerotherm               |
| 16A      | Boiler outlet   | Reload      | 89     | 7.0                     | 32                    | Aerotherm               |
| 16B      | ESP outlet      | Reload      | 89     | 7.0                     | 32                    | Aerotherm               |
| 30       | Boiler outlet   | Hatfield    | 78     | 6.0                     | 28                    | Battelle                |
| 31       | Boiler outlet   | Kentucky C. | 77     | 6.0                     | 25                    | Battelle                |
| 33       | Boiler outlet   | Southeast   | 79     | 6.1                     | 25                    | Battelle                |

All SASS test results will be reported under separate cover at the conclusion of this test program. The SASS sample catches will be analyzed by combined gas chromatography/mass spectroscopy for total polynuclear content. In addition, seven specific polynuclear aromatic hydrocarbons (PAH) will be sought. These are given in Table 5-9.

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TABLE 5-9. POLYNUCLEAR AROMATIC HYDROCARBONS  
ANALYZED IN SITE B SASS SAMPLES

| Element Name                     | Molecular Weight | Molecular Formula                 |
|----------------------------------|------------------|-----------------------------------|
| 7,12 Dimethylbenz (a) anthracene | 256              | C <sub>20</sub> H <sub>16</sub>   |
| Dibenz (a,h) anthracene          | 278              | C <sub>22</sub> H <sub>14</sub>   |
| Benzo (c) phenanthrene           | 228              | C <sub>18</sub> H <sub>12</sub>   |
| 3-methyl cholanthrene            | 268              | C <sub>21</sub> H <sub>16</sub>   |
| Benzo (a) pyrene                 | 252              | C <sub>20</sub> H <sub>12</sub>   |
| Dibenzo (a,h) pyrene             | 302              | C <sub>24</sub> H <sub>14</sub>   |
| Dibenzo (a,i) pyrene             | 302              | C <sub>24</sub> H <sub>14</sub>   |
| Dibenzo (c,g) carbazole          | 267              | C <sub>20</sub> H <sub>13</sub> N |

Tables 5-10 through 5-19 summarize the test data obtained at Test Site B. These tables, in conjunction with Table 2-1 in the Executive Summary, are included for reference purposes.

TABLE 5-10. PARTICULATE EMISSIONS SUMMARY  
TEST SITE B

|               | Test No. | Coal* | Load % | O <sub>2</sub> % | EMISSIONS              |        |       | Velocity ft/sec |
|---------------|----------|-------|--------|------------------|------------------------|--------|-------|-----------------|
|               |          |       |        |                  | lb/10 <sup>6</sup> BTU | gr/SCF | lb/hr |                 |
| BOILER OUTLET | 2        | K     | 28     | 11.3             | 6.57                   | 2.16   | 572   | 16.37           |
|               | 3        | H     | 27     | 10.9             | 8.88                   | 3.53   | 783   | 16.51           |
|               | 4        | K     | 47     | 8.0              | 9.65                   | 4.26   | 1374  | 19.71           |
|               | 6        | S     | 75     | 5.2              | 11.65                  | 6.25   | 2461  | 27.23           |
|               | 7        | S     | 76     | 4.4              | 10.28                  | 5.79   | 2635  | 25.97           |
|               | 8        | K     | 75     | 10.2             | 15.51                  | 5.67   | 3274  | 31.95           |
|               | 9        | K     | 73     | 6.9              | 8.16                   | 3.90   | 1787  | 25.71           |
|               | 11       | R     | 48     | 8.8              | 7.21                   | 2.98   | 1006  | 22.25           |
|               | 12       | R     | 49     | 8.0              | 9.57                   | 4.22   | 1417  | 18.96           |
|               | 15       | R     | 87     | 4.3              | 12.53                  | 7.10   | 3129  | 27.30           |
|               | 16       | R     | 89     | 7.0              | 14.63                  | 6.94   | 3652  | 37.52           |
|               | 17       | R     | 88     | 6.6              | 10.66                  | 5.20   | 2582  | 34.72           |
|               | 18       | S     | 74     | 6.5              | 12.76                  | 6.28   | 2843  | 28.05           |
|               | 19       | K     | 75     | 4.7              | 10.53                  | 5.82   | 2197  | 26.13           |
|               | 20       | K     | 73     | 6.8              | 10.81                  | 5.20   | 2191  | 28.16           |
|               | 21       | H     | 73     | 6.8              | 9.25                   | 4.45   | 1907  | 29.14           |
|               | 22       | H     | 72     | 6.3              | 12.27                  | 6.11   | 2558  | 26.77           |
|               | 23       | K     | 99     | 5.5              | 9.59                   | 5.04   | 2711  | 39.80           |
|               | 24       | S     | 99     | 5.1              | 13.88                  | 7.49   | 3874  | 34.35           |
|               | 25       | K     | 100    | 5.3              | 15.75                  | 8.39   | 4608  | 37.61           |
|               | 26       | H     | 99     | 5.3              | 12.67                  | 6.75   | 3616  | 36.26           |
|               | 27       | K     | 79     | 6.4              | 11.75                  | 5.82   | 2502  | 29.64           |
|               | 28       | K     | 81     | 6.5              | 9.98                   | 4.91   | 2219  | 30.95           |

|                             |    |   |     |      |       |       |     |       |
|-----------------------------|----|---|-----|------|-------|-------|-----|-------|
| MECHANICAL COLLECTOR OUTLET | 3  | H | 27  | 10.9 | 0.543 | 0.193 | 48  | 20.04 |
|                             | 4  | K | 47  | 8.0  | 0.446 | 0.199 | 63  | 24.39 |
|                             | 6  | S | 75  | 5.2  | 0.469 | 0.265 | 99  | 32.11 |
|                             | 7  | S | 76  | 4.4  | 0.755 | 0.423 | 194 | 31.70 |
|                             | 8  | K | 75  | 10.2 | 0.830 | 0.326 | 175 | 39.23 |
|                             | 9  | K | 73  | 6.9  | 0.518 | 0.263 | 113 | 32.11 |
|                             | 11 | R | 48  | 8.8  | 0.481 | 0.189 | 67  | 25.11 |
|                             | 12 | R | 49  | 8.0  | 0.500 | 0.205 | 74  | 24.62 |
|                             | 17 | R | 88  | 6.6  | 0.467 | 0.244 | 113 | 41.02 |
|                             | 18 | S | 74  | 6.5  | 0.810 | 0.398 | 180 | 31.81 |
|                             | 19 | K | 75  | 4.7  | 0.563 | 0.311 | 117 | 30.28 |
|                             | 20 | K | 73  | 6.8  | 0.561 | 0.270 | 114 | 33.82 |
|                             | 21 | H | 73  | 6.8  | 0.619 | 0.298 | 128 | 34.06 |
|                             | 22 | H | 72  | 6.3  | 0.824 | 0.411 | 172 | 31.93 |
|                             | 23 | K | 99  | 5.5  | 0.485 | 0.255 | 137 | 44.29 |
|                             | 24 | S | 99  | 5.1  | 3.530 | 1.910 | 985 | 42.56 |
|                             | 25 | K | 100 | 5.3  | 0.596 | 0.317 | 174 | 43.72 |
|                             | 26 | H | 99  | 5.3  | 0.635 | 0.338 | 181 | 38.60 |
|                             | 27 | K | 79  | 6.4  | 0.591 | 0.293 | 126 | 36.12 |
|                             | 28 | K | 81  | 6.5  | 0.343 | 0.169 | 76  | 35.60 |

|         |    |   |    |     |       |       |   |       |
|---------|----|---|----|-----|-------|-------|---|-------|
| ESP OUT | 15 | R | 87 | 4.3 | 0.023 | 0.012 | 6 | 52.48 |
|         | 16 | R | 89 | 7.0 | 0.018 | 0.008 | 4 | 66.71 |

\* K - Kentucky Cumberland Coal  
H - Hatfield Coal

S - Southeast Coal  
R - Coal Reloaded from Dead Storage

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TABLE 5-11. SUMMARY OF HEAT LOSSES AND EFFICIENCIES,  
TEST SITE B

|                             | TEST NO. | DRY GAS | MOISTURE<br>IN FUEL | H <sub>2</sub> O FROM COM-<br>BUSTION OF H <sub>2</sub> | COMBUSTIBLES IN<br>MECH COLLECTED ASH | COMBUSTIBLES<br>IN FLYASH | COMBUSTIBLES IN<br>BOTTOM ASH | TOTAL COMBUSTIBLES<br>IN REFUSE | RADIATION FROM<br>BOILER | UNMEASURED | TOTAL LOSSES | EFFICIENCY |
|-----------------------------|----------|---------|---------------------|---------------------------------------------------------|---------------------------------------|---------------------------|-------------------------------|---------------------------------|--------------------------|------------|--------------|------------|
| KENTUCKY<br>CUMBERLAND COAL | 4        | 8.88    | 0.14                | 4.26                                                    | 3.76                                  | 0.19                      | 1.21                          | 5.16                            | 0.81                     | 1.50       | 20.75        | 79.25      |
|                             | 8        | 12.00   | 0.40                | 4.11                                                    | 3.04                                  | 0.19                      | 0.64                          | 3.87                            | 0.50                     | 1.50       | 22.38        | 77.62      |
|                             | 9        | 8.32    | 0.45                | 4.23                                                    | 2.85                                  | 0.17                      | 1.07                          | 4.09                            | 0.52                     | 1.50       | 19.11        | 80.89      |
|                             | 19       | 7.93    | 0.32                | 4.20                                                    | 5.38                                  | 0.28                      | 0.54                          | 6.20                            | 0.49                     | 1.50       | 20.64        | 79.36      |
|                             | 20       | 8.26    | 0.46                | 4.41                                                    | 6.53                                  | 0.27                      | 0.45                          | 7.25                            | 0.51                     | 1.50       | 22.38        | 77.61      |
|                             | 23       | 7.96    | 0.52                | 4.42                                                    | 8.09                                  | 0.24                      | 1.01                          | 7.48                            | 0.38                     | 1.50       | 23.85        | 76.15      |
|                             | 25       | 7.66    | 0.27                | 4.21                                                    | 6.76                                  | 0.24                      | 0.64                          | 7.64                            | 0.38                     | 1.50       | 21.66        | 78.34      |
|                             | 27       | 8.05    | 0.48                | 4.28                                                    | 4.41                                  | 0.30                      | 0.04                          | 4.75                            | 0.46                     | 1.50       | 19.52        | 80.48      |
|                             | 28       | 7.68    | 0.54                | 4.24                                                    | 4.84                                  | 0.16                      | 0.80                          | 5.80                            | 0.46                     | 1.50       | 20.22        | 79.78      |
| HATFIELD<br>COAL            | 3        | 11.40   | 0.18                | 4.14                                                    | 4.17                                  | 0.27                      | 0.42                          | 4.86                            | 1.42                     | 1.50       | 23.50        | 76.50      |
|                             | 21       | 8.82    | 0.45                | 4.40                                                    | 3.84                                  | 0.26                      | 0.34                          | 4.44                            | 0.50                     | 1.50       | 20.11        | 79.89      |
|                             | 22       | 7.61    | 0.55                | 4.41                                                    | 6.64                                  | 0.39                      | 2.02                          | 9.05                            | 0.52                     | 1.50       | 23.64        | 76.36      |
|                             | 26       | 7.78    | 0.30                | 4.23                                                    | 4.60                                  | 0.25                      | 0.74                          | 5.59                            | 0.38                     | 1.50       | 19.78        | 80.22      |
| SOUTHEAST<br>COAL           | 6        | 7.30    | 0.18                | 4.36                                                    | 6.68                                  | 0.45                      | 0.73                          | 7.86                            | 0.49                     | 1.50       | 21.69        | 78.31      |
|                             | 7        | 7.20    | 0.09                | 4.06                                                    | 4.55                                  | 0.25                      | 0.38                          | 5.18                            | 0.49                     | 1.50       | 18.52        | 81.48      |
|                             | 18       | 7.93    | 0.32                | 4.20                                                    | 6.38                                  | 0.28                      | 0.15                          | 6.81                            | 0.50                     | 1.50       | 21.26        | 78.74      |
|                             | 24       | 7.34    | 0.52                | 4.17                                                    | 5.18                                  | 3.11                      | 2.29                          | 10.58                           | 0.38                     | 1.50       | 24.49        | 75.51      |
| COAL FROM<br>DEAD STORAGE   | 11       | 9.63    | 0.17                | 4.09                                                    | 3.15                                  | 0.25                      | 0.08                          | 3.49                            | 0.80                     | 1.50       | 19.68        | 80.32      |
|                             | 12       | 8.80    | 0.43                | 4.30                                                    | 3.61                                  | 0.17                      | 0.14                          | 3.92                            | 0.78                     | 1.50       | 19.73        | 80.27      |
|                             | 15       | 6.53    | 0.50                | 4.14                                                    | --                                    | --                        | --                            | --                              | 0.43                     | 1.50       | --           | --         |
|                             | 16       | 8.34    | 0.61                | 4.15                                                    | --                                    | --                        | --                            | --                              | 0.42                     | 1.50       | --           | --         |
|                             | 17       | 8.41    | 0.29                | 4.29                                                    | 7.55                                  | 0.26                      | 0.16                          | 7.97                            | 0.42                     | 1.50       | 22.88        | 77.12      |
|                             |          |         |                     |                                                         |                                       |                           |                               |                                 |                          |            |              |            |

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TABLE 5-12. SUMMARY OF PERCENT COMBUSTIBLES IN REFUSE,  
TEST SITE B

|                           | Test<br>Number | Boiler<br>Outlet | Mechanical<br>Collector<br>Outlet | Mechanical<br>Collector<br>Hopper | Bottom<br>Ash |
|---------------------------|----------------|------------------|-----------------------------------|-----------------------------------|---------------|
| KENTUCKY CUMBERLAND COAL  | 2              | 59.2             | --                                | 63.0                              | 8.2           |
|                           | 4              | 55.2             | --                                | 50.9                              | 19.1          |
|                           | 8              | 59.7             | 15.4                              | 31.6                              | 24.2          |
|                           | 9              | 61.6             | 21.9                              | 55.3                              | 24.2          |
|                           | 19             | 62.0             | 28.8                              | 62.9                              | 10.0          |
|                           | 20             | 65.1             | 28.0                              | 76.6                              | 6.5           |
|                           | 23             | 60.9             | 26.7                              | 79.5                              | 14.2          |
|                           | 25             | 47.0             | 25.0                              | 56.7                              | 9.9           |
|                           | 27             | 57.3             | 28.3                              | 47.2                              | 6.4           |
|                           | 28             | 70.3             | 29.2                              | 60.2                              | 23.4          |
|                           | 31             | --               | --                                | 76.1                              | 13.6          |
|                           | AVERAGE        | 59.8             | 25.4                              | 60.0                              | 14.5          |
| HATFIELD COAL             | 3              | 43.4             | --                                | 48.6                              | 5.4           |
|                           | 21             | 55.2             | 25.2                              | 52.9                              | 6.7           |
|                           | 22             | 53.3             | 28.9                              | 73.9                              | 25.8          |
|                           | 26             | 57.1             | 26.6                              | 47.7                              | 17.6          |
|                           | 30             | --               | --                                | 54.2                              | 16.5          |
|                           | AVERAGE        | 52.3             | 26.9                              | 55.5                              | 14.4          |
| SOUTHEAST COAL            | 6              | 59.8             | 51.8                              | 68.0                              | 9.7           |
|                           | 7              | 67.6             | 22.3                              | 65.9                              | --            |
|                           | 18             | 64.2             | 22.4                              | 65.2                              | 8.9           |
|                           | 24             | 55.3             | 53.1                              | 62.0                              | 13.6          |
|                           | 33             | --               | --                                | 74.8                              | 8.7           |
|                           | AVERAGE        | 61.7             | 37.4                              | 67.2                              | 10.2          |
| COAL FROM<br>DEAD STORAGE | 11             | 64.0             | 33.7                              | 53.9                              | 4.0           |
|                           | 12             | 62.6             | 23.0                              | 53.9                              | 4.0           |
|                           | 15             | 69.0             | --                                | --                                | --            |
|                           | 16             | 74.9             | --                                | --                                | --            |
|                           | 17             | 62.8             | 23.6                              | 66.0                              | 5.7           |
|                           | AVERAGE        | 66.7             | 26.8                              | 57.9                              | 4.6           |

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TABLE 5-13. COAL SIZING SUMMARY, TEST SITE B

|                           | Test<br>Number | PERCENT PASSING STATED SCREEN SIZE |      |      |    |     |
|---------------------------|----------------|------------------------------------|------|------|----|-----|
|                           |                | 1"                                 | 1/2" | 1/4" | #8 | #16 |
| KENTUCKY CUMBERLAND COAL  | 1*             | 93                                 | 56   | 23   | 6  | 0   |
|                           | 2*             | 93                                 | 66   | 26   | 6  | 0   |
|                           | 4              | 92                                 | 63   | 30   | 14 | 9   |
|                           | 8              | 94                                 | 44   | 21   | 14 | 11  |
|                           | 9              | 94                                 | 52   | 28   | 14 | 9   |
|                           | 19             | 94                                 | 57   | 25   | 12 | 9   |
|                           | 20             | 95                                 | 63   | 28   | 12 | 7   |
|                           | 23             | 95                                 | 68   | 36   | 17 | 11  |
|                           | 25             | 95                                 | 52   | 25   | 11 | 8   |
|                           | 27             | 97                                 | 46   | 20   | 10 | 7   |
|                           | 28             | 97                                 | 52   | 23   | 12 | 8   |
|                           | 31             | 93                                 | 59   | 31   | 14 | 9   |
|                           | AVERAGE        | 95                                 | 56   | 27   | 13 | 9   |
| HATFIELD COAL             | 3              | 97                                 | 72   | 42   | 15 | 5   |
|                           | 5              | 96                                 | 73   | 39   | 18 | 11  |
|                           | 21             | 87                                 | 47   | 21   | 10 | 7   |
|                           | 22             | 95                                 | 67   | 36   | 17 | 11  |
|                           | 26             | 97                                 | 73   | 41   | 20 | 12  |
|                           | 30             | 97                                 | 58   | 29   | 15 | 10  |
|                           | AVERAGE        | 95                                 | 65   | 34   | 16 | 9   |
| SOUTHEAST<br>COAL         | 6              | 94                                 | 46   | 23   | 12 | 8   |
|                           | 7              | 97                                 | 62   | 32   | 14 | 9   |
|                           | 24             | 96                                 | 55   | 26   | 13 | 9   |
|                           | 33             | 96                                 | 57   | 26   | 12 | 8   |
|                           | AVERAGE        | 96                                 | 55   | 27   | 13 | 8   |
| COAL FROM<br>DEAD STORAGE | 11             | 97                                 | 44   | 19   | 9  | 6   |
|                           | 12             | 95                                 | 52   | 27   | 14 | 9   |
|                           | 15             | 94                                 | 55   | 29   | 15 | 11  |
|                           | 16             | 95                                 | 63   | 35   | 21 | 11  |
|                           | 17             | 90                                 | 27   | 12   | 6  | 4   |
|                           | AVERAGE        | 94                                 | 48   | 24   | 13 | 8   |

\*Test No. 1 & 2 - Coal was not dried before screening. These two not included in average.

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TABLE 5-14. FUEL ANALYSIS SUMMARY, KENTUCKY CUMBERLAND COAL,  
TEST SITE B

| TEST NO.                     | 1     | 2     | 4     | 8     | 9     | 19    | 20    | 23    | 25    | 27    | 28    | 31    | AVG   | STD<br>DEV |
|------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------------|
| <u>PROXIMATE (as rec.)</u>   |       |       |       |       |       |       |       |       |       |       |       |       |       |            |
| % Moisture                   | 2.99  | 3.45  | 1.60  | 4.39  | 5.05  | 4.75  | 4.95  | 5.56  | 2.90  | 5.30  | 5.98  | 4.36  | 4.27  | 1.29       |
| % Ash                        | 7.58  | 7.15  | 8.85  | 8.83  | 5.92  | 8.00  | 8.22  | 7.60  | 10.66 | 5.83  | 5.81  | 8.18  | 7.72  | 1.43       |
| % Volatile                   | 34.82 | 34.94 | 34.92 | 33.97 | 34.90 | 32.53 | 33.81 | 33.31 | 35.38 | 33.97 | 33.88 | 34.43 | 34.24 | 0.82       |
| % Fixed Carbon               | 54.61 | 54.46 | 54.63 | 52.81 | 54.13 | 54.72 | 53.02 | 53.53 | 51.06 | 54.90 | 54.33 | 53.03 | 53.77 | 1.13       |
| BTU/lb                       | 13426 | 13367 | 13485 | 13111 | 13434 | 13115 | 12972 | 13077 | 12923 | 13266 | 13318 | 13150 | 13220 | 188        |
| % Sulfur                     | 0.80  | 0.91  | 0.84  | 1.05  | 0.93  | 0.87  | 1.06  | 0.91  | 0.91  | 0.68  | 0.87  | 0.93  | 0.90  | 0.10       |
| <u>ULTIMATE (as rec.)</u>    |       |       |       |       |       |       |       |       |       |       |       |       |       |            |
| % Moisture                   |       |       |       | 4.39  |       |       |       |       | 2.90  |       |       | 4.36  | 3.88  | 0.85       |
| % Carbon                     |       |       |       | 72.66 |       |       |       |       | 72.27 |       |       | 73.29 | 72.74 | 0.51       |
| % Hydrogen                   |       |       |       | 4.96  |       |       |       |       | 4.98  |       |       | 4.81  | 4.92  | 0.09       |
| % Nitrogen                   |       |       |       | 0.85  |       |       |       |       | 1.19  |       |       | 1.10  | 1.05  | 0.18       |
| % Chlorine                   |       |       |       | 0.15  |       |       |       |       | 0.07  |       |       | 0.07  | 0.10  | 0.05       |
| % Sulfur                     |       |       |       | 1.05  |       |       |       |       | 0.91  |       |       | 0.93  | 0.96  | 0.08       |
| % Ash                        |       |       |       | 8.83  |       |       |       |       | 10.66 |       |       | 8.18  | 9.22  | 1.29       |
| % Oxygen (diff.)             |       |       |       | 7.11  |       |       |       |       | 7.02  |       |       | 7.26  | 7.13  | 0.12       |
| <u>ASH FUSION (reducing)</u> |       |       |       |       |       |       |       |       |       |       |       |       |       |            |
| Initial Deformation          |       |       |       | 2320  |       |       |       |       | 2450  |       |       | 2700+ | 2490  | 193        |
| Soft. (H=H)                  |       |       |       | 2570  |       |       |       |       | 2660  |       |       | 2700+ | 2643  | 67         |
| Soft. (H=1/2H)               |       |       |       | 2620  |       |       |       |       | 2700+ |       |       | 2700+ | 2673  | 46         |
| Fluid                        |       |       |       | 2700+ |       |       |       |       | 2700+ |       |       | 2700+ | 2700  | 0          |

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TABLE 5-15. FUEL ANALYSIS SUMMARY, HATFIELD COAL, TEST SITE B

| TEST NO.                     | 3     | 5     | 21    | 22    | 26    | 30    | 32    | AVG   | STD<br>DEV |
|------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|------------|
| <u>PROXIMATE (as rec.)</u>   |       |       |       |       |       |       |       |       |            |
| % Moisture                   | 1.90  | 1.66  | 4.81  | 5.89  | 3.25  | 4.71  | 5.31  | 3.93  | 1.68       |
| % Ash                        | 11.38 | 8.78  | 8.42  | 8.26  | 8.53  | 8.35  | 7.79  | 8.79  | 1.18       |
| % Volatile                   | 34.44 | 34.22 | 33.42 | 33.05 | 34.35 | 32.73 | 33.35 | 33.65 | 0.68       |
| % Fixed Carbon               | 52.28 | 55.34 | 53.35 | 52.80 | 53.87 | 54.21 | 53.55 | 53.63 | 0.99       |
| BTU/LB                       | 12960 | 13472 | 13097 | 12926 | 13235 | 13222 | 13049 | 13137 | 189        |
| % Sulfur                     | 0.98  | 0.89  | 0.89  | 0.91  | 0.95  | 0.87  | 0.99  | 0.93  | 0.05       |
| <u>ULTIMATE (as rec.)</u>    |       |       |       |       |       |       |       |       |            |
| % Moisture                   | 1.90  |       |       |       |       |       |       | 3.31  | 1.99       |
| % Carbon                     | 72.15 |       |       |       |       |       |       | 72.88 | 1.03       |
| % Hydrogen                   | 4.97  |       |       |       |       |       |       | 4.88  | 0.13       |
| % Nitrogen                   | 1.48  |       |       |       |       |       |       | 1.43  | 0.07       |
| % Chlorine                   | 0.08  |       |       |       |       |       |       | 0.10  | 0.02       |
| % Sulfur                     | 0.98  |       |       |       |       |       |       | 0.93  | 0.08       |
| % Ash                        | 11.38 |       |       |       |       |       |       | 9.87  | 2.14       |
| % Oxygen (diff.)             | 7.06  |       |       |       |       |       |       | 6.62  | 0.62       |
| <u>ASH FUSION (reducing)</u> |       |       |       |       |       |       |       |       |            |
| Initial Deformation          | 2400  |       |       |       |       |       |       | 2550  | 212        |
| Soft. (H=W)                  | 2700+ |       |       |       |       |       |       | 2700+ | 0          |
| Soft. (H=1/2W)               | 2700+ |       |       |       |       |       |       | 2700+ | 0          |
| Fluid                        | 2700+ |       |       |       |       |       |       | 2700+ | 0          |

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TABLE 5-16. FUEL ANALYSIS SUMMARY, SOUTHEAST COAL, TEST SITE B

| TEST NO.                     | 6     | 7     | 18    | 24    | 33    | AVG   | STD<br>DEV |
|------------------------------|-------|-------|-------|-------|-------|-------|------------|
| <u>PROXIMATE (as rec.)</u>   |       |       |       |       |       |       |            |
| % Moisture                   | 1.99  | 1.08  | 3.64  | 5.03  | 2.75  | 2.90  | 1.52       |
| % Ash                        | 9.41  | 6.48  | 5.66  | 16.79 | 6.77  | 9.02  | 4.56       |
| % Volatile                   | 33.95 | 35.60 | 35.24 | 30.97 | 35.17 | 34.19 | 1.90       |
| % Fixed Carbon               | 54.65 | 56.84 | 55.46 | 47.21 | 55.31 | 53.89 | 3.82       |
| BTU/LB                       | 13011 | 13981 | 13696 | 11667 | 13649 | 13201 | 928        |
| % Sulfur                     | 0.83  | 0.82  | 0.71  | 0.75  | 0.79  | 0.78  | 0.05       |
| <u>ULTIMATE (as rec.)</u>    |       |       |       |       |       |       |            |
| % Moisture                   |       | 1.08  |       | 5.03  | 2.75  | 2.95  | 1.98       |
| % Carbon                     |       | 78.08 |       | 65.56 | 76.37 | 73.34 | 6.79       |
| % Hydrogen                   |       | 5.25  |       | 4.44  | 5.06  | 4.92  | 0.42       |
| % Nitrogen                   |       | 1.37  |       | 1.30  | 1.11  | 1.26  | 0.13       |
| % Chlorine                   |       | 0.13  |       | 0.10  | 0.15  | 0.13  | 0.03       |
| % Sulfur                     |       | 0.82  |       | 0.75  | 0.79  | 0.79  | 0.04       |
| % Ash                        |       | 6.48  |       | 16.79 | 6.77  | 10.01 | 5.87       |
| % Oxygen (diff.)             |       | 6.79  |       | 6.03  | 7.00  | 6.61  | 0.51       |
| <u>ASH FUSION (reducing)</u> |       |       |       |       |       |       |            |
| Initial Deformation          |       | 2700+ |       | 2520  | 2600  | 2607  | 90         |
| Soft. (H=W)                  |       | 2700+ |       | 2700+ | 2700+ | 2700+ | 0          |
| Soft. (H=1/2W)               |       | 2700+ |       | 2700+ | 2700+ | 2700+ | 0          |
| Fluid                        |       | 2700+ |       | 2700+ | 2700+ | 2700+ | 0          |

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TABLE 5-17. FUEL ANALYSIS SUMMARY, COAL FROM DEAD STORAGE, TEST SITE B

| TEST NO.                     | 11    | 12    | 15    | 16    | 17    | AVG   | STD<br>DEV |
|------------------------------|-------|-------|-------|-------|-------|-------|------------|
| <u>PROXIMATE (as rec.)</u>   |       |       |       |       |       |       |            |
| % Moisture                   | 1.99  | 4.76  | 5.48  | 6.46  | 3.20  | 4.38  | 1.79       |
| % Ash                        | 5.08  | 6.50  | 6.47  | 6.96  | 6.99  | 6.40  | 0.78       |
| % Volatile                   | 35.44 | 34.88 | 34.21 | 33.73 | 35.28 | 34.71 | 0.72       |
| % Fixed Carbon               | 57.49 | 53.86 | 53.84 | 52.85 | 54.53 | 54.51 | 1.77       |
| BTU/LB                       | 14077 | 13368 | 13181 | 13001 | 13535 | 13432 | 412        |
| % Sulfur                     | 0.75  | 0.85  | 0.71  | 0.75  | 0.77  | 0.77  | 0.05       |
| <u>ULTIMATE (as rec.)</u>    |       |       |       |       |       |       |            |
| % Moisture                   |       | 5.48  |       | 6.46  |       | 5.97  | 0.69       |
| % Carbon                     |       | 74.11 |       | 72.78 |       | 73.45 | 0.94       |
| % Hydrogen                   |       | 4.99  |       | 4.88  |       | 4.94  | 0.08       |
| % Nitrogen                   |       | 1.44  |       | 1.45  |       | 1.45  | 0.01       |
| % Chlorine                   |       | 0.12  |       | 0.11  |       | 0.12  | 0.01       |
| % Sulfur                     |       | 0.71  |       | 0.75  |       | 0.73  | 0.03       |
| % Ash                        |       | 6.47  |       | 6.96  |       | 6.72  | 0.35       |
| % Oxygen (diff.)             |       | 6.68  |       | 6.61  |       | 6.65  | 0.05       |
| <u>ASH FUSION (reducing)</u> |       |       |       |       |       |       |            |
| Initial Deformation          |       | 2700+ |       | 2700+ |       | 2700+ | 0          |
| Soft. (H=H)                  |       | 2700+ |       | 2700+ |       | 2700+ | 0          |
| Soft. (H=1/2W)               |       | 2700+ |       | 2700+ |       | 2700+ | 0          |
| Fluid                        |       | 2700+ |       | 2700+ |       | 2700+ | 0          |

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TABLE 5-18

SUMMARY OF MINERAL ANALYSIS OF COAL ASH  
TEST SITE B

| Test No.                                      | Kentucky<br>Cumberland |       |       | Hatfield |       | Southeast |       |       | Reload from<br>Long Term<br>Storage |       |
|-----------------------------------------------|------------------------|-------|-------|----------|-------|-----------|-------|-------|-------------------------------------|-------|
|                                               | 8                      | 25    | 31    | 3        | 30    | 7         | 24    | 33    | 15                                  | 16    |
| Silica, SiO <sub>2</sub>                      | 54.44                  | 54.90 | 52.64 | 53.99    | 55.65 | 53.39     | 54.90 | 54.14 | 54.14                               | 53.39 |
| Alumina, Al <sub>2</sub> O <sub>3</sub>       | 26.78                  | 27.14 | 31.40 | 27.85    | 29.30 | 30.71     | 28.56 | 29.99 | 30.00                               | 30.71 |
| Titania, TiO <sub>2</sub>                     | 0.99                   | 1.10  | 1.54  | 1.21     | 1.76  | 1.54      | 1.21  | 1.65  | 1.43                                | 1.32  |
| Ferric Oxide, Fe <sub>2</sub> O <sub>3</sub>  | 9.29                   | 7.22  | 6.44  | 8.26     | 6.34  | 6.41      | 7.74  | 6.60  | 6.35                                | 7.22  |
| Lime, CaO                                     | 2.02                   | 2.80  | 1.90  | 1.85     | 1.40  | 1.90      | 1.95  | 2.00  | 1.90                                | 1.97  |
| Magnesia, MgO                                 | 1.43                   | 1.32  | 1.05  | 1.32     | 0.87  | 0.75      | 1.08  | 0.68  | 0.81                                | 0.90  |
| Potassium Oxide, K <sub>2</sub> O             | 2.50                   | 1.95  | 2.30  | 2.20     | 2.15  | 1.15      | 1.95  | 1.23  | 1.55                                | 1.85  |
| Sodium Oxide, Na <sub>2</sub> O               | 0.52                   | 0.52  | 0.63  | 0.42     | 0.77  | 0.62      | 0.42  | 0.47  | 0.47                                | 0.42  |
| Sulfur Trioxide, SO <sub>3</sub>              | 1.42                   | 1.71  | 1.05  | 1.18     | 0.86  | 1.13      | 1.17  | 1.15  | 1.43                                | 1.43  |
| Phos Pentoxide, P <sub>2</sub> O <sub>5</sub> | 0.23                   | 0.17  | 0.44  | 0.40     | 0.38  | 0.50      | 0.23  | 0.62  | 0.28                                | 0.31  |
| Undetermined                                  | 0.38                   | 1.17  | 0.61  | 1.32     | 0.52  | 1.90      | 0.79  | 1.47  | 1.64                                | 0.48  |
|                                               | 100.0                  | 100.0 | 100.0 | 100.0    | 100.0 | 100.0     | 100.0 | 100.0 | 100.0                               | 100.0 |
| Alk as Na <sub>2</sub> O                      | 0.20                   | 0.20  | --    | 0.22     | --    | 0.09      | 0.30  | --    | 0.10                                | 0.12  |
| Silica Value                                  | 81.04                  | 82.88 | 84.86 | 82.53    | 86.60 | 85.49     | 83.60 | 85.37 | 85.66                               | 81.20 |
| Base/Acid                                     | 0.19                   | 0.17  | 0.14  | 0.17     | 0.13  | 0.13      | 0.16  | 0.13  | 0.13                                | 0.14  |
| T <sub>250</sub> Poises                       | 2755                   | 2810  | 2870  | 2800     | 2900+ | 2900+     | 2830  | 2900+ | 2900+                               | 2850  |
| % Pyritic Sulfur                              | --                     | --    | 0.20  | --       | 0.18  | --        | --    | 0.17  | --                                  | --    |
| % Sulfate Sulfur                              | --                     | --    | 0.00  | --       | 0.03  | --        | --    | 0.02  | --                                  | --    |
| % Organic Sulfur                              | --                     | --    | 0.73  | --       | 0.66  | --        | --    | 0.60  | --                                  | --    |

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TABLE 5-19. SUMMARY OF STEAM FLOWS AND HEAT RELEASE RATES,  
TEST SITE B

| Test No. | Capacity<br>% | Steam Flow<br>10 <sup>3</sup> lb/hr | Heat Input<br>10 <sup>6</sup> BTU/hr | Heat Output<br>10 <sup>6</sup> BTU/hr | Front Foot<br>Heat Release<br>10 <sup>4</sup> BTU/ft <sup>2</sup> /hr | Grate<br>Heat Release<br>10 <sup>3</sup> BTU/ft <sup>2</sup> /hr | Furnace<br>Heat Release<br>10 <sup>2</sup> BTU/ft <sup>2</sup> /hr |
|----------|---------------|-------------------------------------|--------------------------------------|---------------------------------------|-----------------------------------------------------------------------|------------------------------------------------------------------|--------------------------------------------------------------------|
| 1        | 41.1          | 82.1                                | 123.6                                | 88.8                                  | 616.9                                                                 | 334.0                                                            | 95.7                                                               |
| 2        | 27.7          | 55.3                                | 87.1                                 | 59.8                                  | 434.9                                                                 | 235.4                                                            | 67.5                                                               |
| 3        | 27.2          | 54.3                                | 88.1                                 | 58.3                                  | 440.0                                                                 | 238.2                                                            | 68.3                                                               |
| 4        | 47.3          | 94.6                                | 142.4                                | 102.3                                 | 710.7                                                                 | 384.8                                                            | 110.3                                                              |
| 5        | 46.7          | 93.3                                | 138.8                                | 100.8                                 | 692.9                                                                 | 375.1                                                            | 107.5                                                              |
| 6        | 75.5          | 151.0                               | 211.2                                | 163.2                                 | 1054.4                                                                | 570.8                                                            | 163.6                                                              |
| 7        | 75.8          | 151.7                               | 256.4                                | 163.5                                 | 1279.8                                                                | 692.9                                                            | 198.6                                                              |
| 8        | 74.5          | 149.0                               | 211.1                                | 159.9                                 | 1053.8                                                                | 570.5                                                            | 163.5                                                              |
| 9        | 72.5          | 145.0                               | 219.0                                | 156.8                                 | 1093.2                                                                | 591.8                                                            | 169.6                                                              |
| 10*      | 31.3          | 62.5                                | 95.1                                 | 67.5                                  | 474.9                                                                 | 257.1                                                            | 73.7                                                               |
| 11       | 47.6          | 95.2                                | 139.5                                | 102.8                                 | 696.4                                                                 | 377.0                                                            | 108.1                                                              |
| 12       | 48.7          | 97.4                                | 148.1                                | 105.1                                 | 739.2                                                                 | 400.2                                                            | 114.7                                                              |
| 13*      | 71.6          | 143.2                               | 205.9                                | 156.0                                 | 1027.8                                                                | 556.4                                                            | 159.5                                                              |
| 14*      | 95.7          | 191.5                               | 280.3                                | 209.5                                 | 1399.5                                                                | 757.6                                                            | 217.1                                                              |
| 15       | 87.4          | 174.8                               | 249.7                                | 189.6                                 | 1246.6                                                                | 674.9                                                            | 193.4                                                              |
| 16       | 88.7          | 177.4                               | 249.6                                | 193.0                                 | 1246.1                                                                | 674.6                                                            | 193.4                                                              |
| 17       | 88.3          | 176.7                               | 242.2                                | 193.7                                 | 1209.0                                                                | 654.5                                                            | 187.6                                                              |
| 18       | 73.7          | 147.3                               | 209.1                                | 159.2                                 | 1043.8                                                                | 565.1                                                            | 162.0                                                              |
| 19       | 75.1          | 150.2                               | 208.6                                | 162.8                                 | 1041.5                                                                | 563.8                                                            | 161.6                                                              |
| 20       | 72.8          | 145.6                               | 202.7                                | 158.4                                 | 1012.1                                                                | 547.9                                                            | 157.0                                                              |
| 21       | 72.8          | 145.7                               | 206.1                                | 159.4                                 | 1029.1                                                                | 557.1                                                            | 159.7                                                              |
| 22       | 71.8          | 143.6                               | 208.5                                | 155.7                                 | 1040.9                                                                | 563.5                                                            | 161.5                                                              |
| 23       | 98.9          | 197.9                               | 282.7                                | 216.8                                 | 1411.3                                                                | 764.1                                                            | 219.0                                                              |
| 24       | 98.8          | 197.5                               | 279.1                                | 215.4                                 | 1393.4                                                                | 754.4                                                            | 216.2                                                              |
| 25       | 100.2         | 200.4                               | 292.6                                | 218.5                                 | 1460.6                                                                | 790.7                                                            | 226.6                                                              |
| 26       | 99.0          | 198.0                               | 285.4                                | 215.8                                 | 1424.7                                                                | 771.3                                                            | 221.1                                                              |
| 27       | 79.4          | 158.8                               | 212.9                                | 171.7                                 | 1063.1                                                                | 575.5                                                            | 164.9                                                              |
| 28       | 80.9          | 161.7                               | 222.4                                | 174.6                                 | 1110.1                                                                | 601.0                                                            | 172.2                                                              |
| 30       | 78.1          | 156.3                               | 222.7                                | 169.3                                 | 1111.7                                                                | 601.9                                                            | 172.5                                                              |
| 31       | 77.0          | 153.9                               | 215.1                                | 166.8                                 | 1073.9                                                                | 581.4                                                            | 166.6                                                              |
| 32       | 78.0          | 156.0                               | 211.9                                | 169.0                                 | 1057.6                                                                | 572.6                                                            | 164.1                                                              |
| 33       | 78.8          | 157.6                               | 226.2                                | 170.8                                 | 1129.1                                                                | 611.3                                                            | 175.2                                                              |

\* An average BTU/lb was used, for Test 10 - 13,089  
for Tests 13 & 14 - 13,432

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# APPENDIX A. OVERFIRE AIR FLOW TRAVERSE DATA - TEST SITE B

Pressure Reading With an S Type Pitot Tube  
 Reading in Inches of Water Column  
 Area of Duct = 4.20 ft<sup>2</sup>

| Velocity Point | Maximum<br>Overfire Air<br>(34" H <sub>2</sub> O)<br>$\Delta P$ , in. H <sub>2</sub> O | Minimum<br>Overfire Air<br>(6.5" H <sub>2</sub> O)<br>$\Delta P$ , in. H <sub>2</sub> O |
|----------------|----------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|
| Vertical       |                                                                                        |                                                                                         |
| 1              | 0.60                                                                                   | 0.40                                                                                    |
| 2              | 0.75                                                                                   | 0.45                                                                                    |
| 3              | 0.85                                                                                   | 0.40                                                                                    |
| 4              | 0.85                                                                                   | 0.40                                                                                    |
| 5              | 0.80                                                                                   | 0.45                                                                                    |
| 6              | 0.75                                                                                   | 0.40                                                                                    |
| 7              | 0.65                                                                                   | 0.40                                                                                    |
| 8              | 0.65                                                                                   | 0.45                                                                                    |
| 9              | 0.75                                                                                   | 0.45                                                                                    |
| 10             | 0.85                                                                                   | 0.40                                                                                    |
| 11             | 0.85                                                                                   | 0.40                                                                                    |
| 12             | 0.70                                                                                   | 0.35                                                                                    |
| Horizontal     |                                                                                        |                                                                                         |
| 1              | 0.75                                                                                   | 0.40                                                                                    |
| 2              | 0.80                                                                                   | 0.40                                                                                    |
| 3              | 0.80                                                                                   | 0.50                                                                                    |
| 4              | 0.85                                                                                   | 0.40                                                                                    |
| 5              | 0.85                                                                                   | 0.40                                                                                    |
| 6              | 0.75                                                                                   | 0.40                                                                                    |
| 7              | 0.65                                                                                   | 0.40                                                                                    |
| 8              | 0.65                                                                                   | 0.40                                                                                    |
| 9              | 0.65                                                                                   | 0.45                                                                                    |
| 10             | 0.70                                                                                   | 0.45                                                                                    |
| 11             | 0.65                                                                                   | 0.40                                                                                    |
| 12             | 0.50                                                                                   | 0.35                                                                                    |
| AVERAGE        | 0.7354                                                                                 | 0.4125                                                                                  |

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# APPENDIX B. OVERFIRE AIR FLOW CALCULATION - TEST SITE B

## Maximum Overfire Air (34" H<sub>2</sub>O)

$$\text{Average } \Delta P = 0.7354 \text{ in. H}_2\text{O}$$

$$T_s = 82^\circ \text{ F}$$

$$P_s = 33.46 \text{ in. Hg}$$

$$F_s = 0.86$$

$$G_s = 1.00$$

$$A_s = 4.20 \text{ ft}^2$$

$$V = 174 F_s \sqrt{\Delta P (T_s + 460) \frac{407}{P_s} \frac{1.00}{G_s}}$$

$$= (174) (0.86) \sqrt{(0.7354) (542) \left( \frac{407}{455} \right) \left( \frac{1.00}{1.00} \right)}$$

$$= 2826 \text{ ft/min}$$

$$= 47.09 \text{ ft/sec}$$

$$\text{SCFM} = V A_s \left( \frac{530}{T_s} \right) \left( \frac{P_s}{407} \right)$$

$$= (2826) (4.20) \left( \frac{530}{542} \right) \left( \frac{455}{407} \right)$$

$$= 12,973 \text{ SCFM}$$

$$n = \frac{PV}{RT}$$

$$= \frac{(1) (12,973)}{(0.730) (530)}$$

$$= 33.53 \text{ moles/min}$$

$$= 972.4 \text{ lb/min}$$

$$= 58,344 \text{ lb/hr}$$

## Minimum Overfire Air (6.5" H<sub>2</sub>O)

$$\text{Average } \Delta P = 0.4125 \text{ in. H}_2\text{O}$$

$$T_s = 82^\circ \text{ F}$$

$$P_s = 33.31 \text{ in. Hg}$$

$$F_s = 0.86$$

$$G_s = 1.00$$

$$A_s = 4.20 \text{ ft}^2$$

$$V = (174) (0.86) \sqrt{(0.4125) (542) \left( \frac{407}{453} \right) \left( \frac{1.00}{1.00} \right)}$$

$$= 2121 \text{ ft/min}$$

$$= 35.35 \text{ ft/sec}$$

$$\text{SCFM} = (2121) (4.20) \left( \frac{530}{542} \right) \left( \frac{453}{407} \right)$$

$$= 9,695 \text{ SCFM}$$

$$n = \frac{(1) (9,695)}{(0.730) (530)}$$

$$= 25.06 \text{ moles/min}$$

$$= 726.7 \text{ lb/min}$$

$$= 43,600 \text{ lb/hr}$$

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| Test No. | Load % | O <sub>2</sub> % | Coal <sup>+</sup> | SULFUR IN FUEL          |                                           |              | SULFUR IN BOTTOM ASH*                     |             |              | SULFUR IN FLY ASH**                       |             |                          | SULFUR EMISSIONS                                          |             |             |
|----------|--------|------------------|-------------------|-------------------------|-------------------------------------------|--------------|-------------------------------------------|-------------|--------------|-------------------------------------------|-------------|--------------------------|-----------------------------------------------------------|-------------|-------------|
|          |        |                  |                   | Fuel Sulfur %           | As SO <sub>2</sub> lb/10 <sup>6</sup> BTU | Ash Sulfur % | As SO <sub>2</sub> lb/10 <sup>6</sup> BTU | Retention % | Ash Sulfur % | As SO <sub>2</sub> lb/10 <sup>6</sup> BTU | Retention % | SO <sub>x</sub> ppm(dry) | SO <sub>x</sub> as SO <sub>2</sub> lb/10 <sup>6</sup> BTU | Fuel Sulfur | Fuel Sulfur |
| 1        | 41     | 9.9              | K                 | 0.80                    | 1.192                                     | --           | --                                        | --          | --           | --                                        | --          | 545                      | 1.055                                                     | 89%         |             |
| 15 Blr   | 87     | 4.3              | R                 | 0.71                    | 1.077                                     | --           | --                                        | --          | --           | --                                        | --          | 392                      | 0.755                                                     | 71%         |             |
| 15 ESP   | "      | "                | "                 | "                       | "                                         | --           | --                                        | --          | --           | --                                        | --          | 150                      | 0.289                                                     | 27%         |             |
| 16 Blr   | 89     | 7.0              | R                 | 0.75                    | 1.154                                     | --           | --                                        | --          | --           | --                                        | --          | 469                      | 0.903                                                     | 78%         |             |
| 16 ESP   | "      | "                | "                 | "                       | "                                         | --           | --                                        | --          | --           | --                                        | --          | 273                      | 0.525                                                     | 46%         |             |
| 30 Blr   | 78     | 6.0              | H                 | 0.87                    | 1.316                                     | 0.08         | .0048                                     | 0.37        | 0.07         | .0116                                     | 0.88        | 472                      | 0.922                                                     | 70%         |             |
| 30 ESP   | "      | "                | "                 | "                       | "                                         | 0.03         | .0017                                     | 0.12        | 0.07         | .0219                                     | 1.55        | 367                      | 0.717                                                     | 54%         |             |
| 31 Blr   | 77     | 6.0              | K                 | 0.93                    | 1.414                                     | 0.04         | .0022                                     | 0.15        | 0.08         | .0129                                     | 0.85        | 428                      | 0.828                                                     | 59%         |             |
| 31 ESP   | "      | "                | "                 | "                       | "                                         | 0.03         | .0013                                     | 0.11        | 0.08         | .0189                                     | 1.63        | 391                      | 0.757                                                     | 54%         |             |
| 32 Blr   | 78     | 5.9              | H                 | 0.99                    | 1.517                                     | 0.04         | .0022                                     | 0.15        | 0.08         | .0129                                     | 0.85        | 446                      | 0.871                                                     | 57%         |             |
| 33 Blr   | 79     | 6.1              | S                 | 0.79                    | 1.158                                     | 0.03         | .0013                                     | 0.11        | 0.08         | .0189                                     | 1.63        | 397                      | 0.776                                                     | 67%         |             |
|          |        |                  |                   | Average retention 0.19% |                                           |              | Average retention 1.23%                   |             |              |                                           |             |                          |                                                           |             |             |

+ K - Kentucky Cumberland Coal

H - Hatfield Coal

S - Southeast Coal

R - Releas coal from dead storage

Note: The sulfur oxide sample probe used at test site B may have been defective resulting in lower measured sulfur oxide concentrations than actually existed. Because of this possibility, the site B SO<sub>x</sub> data is presented here in the appendix rather than in the main body of the report.

# APPENDIX C. SULFUR BALANCE SUMMARY - TEST SITE B

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# APPENDIX D

## ENGLISH AND METRIC UNITS TO SI UNITS

| <u>To Convert From</u>  | <u>To</u>           | <u>Multiply By</u> |
|-------------------------|---------------------|--------------------|
| in                      | cm                  | 2.540              |
| in <sup>2</sup>         | cm <sup>2</sup>     | 6.452              |
| ft                      | m                   | 0.3048             |
| ft <sup>2</sup>         | m <sup>2</sup>      | 0.09290            |
| ft <sup>3</sup>         | m <sup>3</sup>      | 0.02832            |
| lb                      | Kg                  | 0.4536             |
| lb/hr                   | Mg/s                | 0.1260             |
| lb/10 <sup>6</sup> BTU  | ng/J                | 430                |
| g/Mcal                  | ng/J                | 239                |
| BTU                     | J                   | 1054               |
| BTU/lb                  | J/kg                | 0.002324           |
| BTU/hr                  | W                   | 0.2929             |
| J/sec                   | W                   | 1.000              |
| J/hr                    | W                   | 3600               |
| BTU/ft/hr               | W/m                 | 0.9609             |
| BTU/ft/hr               | J/hr/m              | 3459               |
| BTU/ft <sup>2</sup> /hr | W/m <sup>2</sup>    | 3.152              |
| BTU/ft <sup>2</sup> /hr | J/hr/m <sup>2</sup> | 11349              |
| BTU/ft <sup>3</sup> /hr | W/m <sup>3</sup>    | 10.34              |
| BTU/ft <sup>3</sup> /hr | J/hr/m <sup>3</sup> | 37234              |
| psia                    | Pa                  | 6895               |
| "H <sub>2</sub> O       | Pa                  | 249.1              |
| Rankine                 | Celsius             | C = 5/9R-273       |
| Fahrenheit              | Celsius             | C = 5/9(F-32)      |
| Celsius                 | Kelvin              | K = C+273          |
| Rankine                 | Kelvin              | K = 5/9R           |

### COAL FUEL ONLY

|                                            |      |       |
|--------------------------------------------|------|-------|
| ppm @ 3% O <sub>2</sub> (SO <sub>2</sub> ) | ng/J | 0.851 |
| ppm @ 3% O <sub>2</sub> (SO <sub>3</sub> ) | ng/J | 1.063 |
| ppm @ 3% O <sub>2</sub> (NO)               | ng/J | 0.399 |
| ppm @ 3% O <sub>2</sub> (NO <sub>2</sub> ) | ng/J | 0.611 |
| ppm @ 3% O <sub>2</sub> (CO)               | ng/J | 0.372 |
| ppm @ 3% O <sub>2</sub> (CH <sub>4</sub> ) | ng/J | 0.213 |

# APPENDIX E

## SI UNITS TO ENGLISH AND METRIC UNITS

| <u>To Convert From</u> | <u>TO</u>               | <u>Multiply By</u> |
|------------------------|-------------------------|--------------------|
| cm                     | in                      | 0.3937             |
| cm <sup>2</sup>        | in <sup>2</sup>         | 0.1550             |
| m                      | ft                      | 3.281              |
| m <sup>2</sup>         | ft <sup>2</sup>         | 10.764             |
| m <sup>3</sup>         | ft <sup>3</sup>         | 35.315             |
| Kg                     | lb                      | 2.205              |
| Mg/s                   | lb/hr                   | 7.937              |
| ng/J                   | lb/10 <sup>6</sup> BTU  | 0.00233            |
| ng/J                   | g/Mcal                  | 0.00418            |
| J                      | BTU                     | 0.000948           |
| J/kg                   | BTU/lb                  | 4.303              |
| J/hr/m                 | BTU/ft/hr               | 0.000289           |
| J/hr/m <sup>2</sup>    | BTU/ft <sup>2</sup> /hr | 0.0000881          |
| J/hr/m <sup>3</sup>    | BTU/ft <sup>3</sup> /hr | 0.0000269          |
| W                      | BTU/hr                  | 3.414              |
| W                      | J/hr                    | 0.000278           |
| W/m                    | BTU/ft/hr               | 1.041              |
| W/m <sup>2</sup>       | BTU/ft <sup>2</sup> /hr | 0.317              |
| W/m <sup>3</sup>       | BTU/ft <sup>3</sup> /hr | 0.0967             |
| Pa                     | psia                    | 0.000145           |
| Pa                     | "H <sub>2</sub> O       | 0.004014           |
| Kelvin                 | Fahrenheit              | F = 1.8K-460       |
| Celsius                | Fahrenheit              | F = 1.8C+32        |
| Fahrenheit             | Rankine                 | R = F+460          |
| Kelvin                 | Rankine                 | R = 1.8K           |

### COAL FUEL ONLY

|      |                                            |       |
|------|--------------------------------------------|-------|
| ng/J | ppm @ 3% O <sub>2</sub> (SO <sub>2</sub> ) | 1.18  |
| ng/J | ppm @ 3% O <sub>2</sub> (SO <sub>3</sub> ) | 0.941 |
| ng/J | ppm @ 3% O <sub>2</sub> (NO)               | 2.51  |
| ng/J | ppm @ 3% O <sub>2</sub> (NO <sub>2</sub> ) | 1.64  |
| ng/J | ppm @ 3% O <sub>2</sub> (CO)               | 2.69  |
| ng/J | ppm @ 3% O <sub>2</sub> (CH <sub>4</sub> ) | 4.69  |

## APPENDIX F

### SI PREFIXES

| <u>Multiplication Factor</u> | <u>Prefix</u> | <u>SI Symbol</u> |
|------------------------------|---------------|------------------|
| $10^{12}$                    | tera          | T                |
| $10^9$                       | giga          | G                |
| $10^6$                       | mega          | M                |
| $10^3$                       | kilo          | k                |
| $10^2$                       | hecto*        | h                |
| $10^1$                       | deka*         | da               |
| $10^{-1}$                    | deci*         | d                |
| $10^{-2}$                    | centi*        | c                |
| $10^{-3}$                    | milli         | m                |
| $10^{-6}$                    | micro         | $\mu$            |
| $10^{-9}$                    | nano          | n                |
| $10^{-12}$                   | pico          | p                |
| $10^{-15}$                   | femto         | f                |
| $10^{-18}$                   | atto          | a                |

\*Not recommended but occasionally used

# APPENDIX G

## EMISSIONS UNITS CONVERSION FACTORS

FOR TYPICAL COAL FUEL (HV = 13,320 BTU/LB)

| Multiply<br>To<br>Obtain                   | Weight In Fuel<br>S | Weight In Fuel<br>N | lbs/10 <sup>6</sup> Btu |                 | grams/10 <sup>6</sup> Cal |                 | PPM<br>(Dry @ 3% O <sub>2</sub> ) |                       | grains/SCF<br>(Dry @ 12% CO <sub>2</sub> ) |                 |
|--------------------------------------------|---------------------|---------------------|-------------------------|-----------------|---------------------------|-----------------|-----------------------------------|-----------------------|--------------------------------------------|-----------------|
|                                            |                     |                     | SO <sub>2</sub>         | NO <sub>2</sub> | SO <sub>2</sub>           | NO <sub>2</sub> | SOx                               | NOx                   | SO <sub>2</sub>                            | NO <sub>2</sub> |
| Weight<br>In Fuel                          | 1                   |                     | 0.666                   |                 |                           |                 | 13.2x10 <sup>-4</sup>             |                       | 1.48                                       |                 |
| Weight<br>In Fuel                          |                     |                     |                         | 0.405           |                           | 0.225           |                                   | 5.76x10 <sup>-4</sup> |                                            | .903            |
| lbs/10 <sup>6</sup> Btu                    | 1.50                |                     |                         |                 |                           |                 | 19.8x10 <sup>-4</sup>             |                       | (2.23)                                     |                 |
| Weight<br>In Fuel                          |                     | 2.47                |                         |                 |                           | (.556)          |                                   |                       |                                            | (2.23)          |
| grams/10 <sup>6</sup> Cal                  | 2.70                |                     | (1.8)                   |                 |                           |                 | 35.6x10 <sup>-4</sup>             |                       | (4.01)                                     |                 |
| Weight<br>In Fuel                          |                     | 4.44                |                         | (1.8)           |                           |                 |                                   | 25.6x10 <sup>-4</sup> |                                            | (4.01)          |
| PPM<br>(Dry @ 3% O <sub>2</sub> )          | 758                 |                     | 505                     |                 |                           |                 |                                   |                       | 1127                                       |                 |
| Weight<br>In Fuel                          |                     | 1736                |                         | 704             |                           | 391             |                                   |                       |                                            | 1566            |
| grains/SCF<br>(Dry @ 12% CO <sub>2</sub> ) | .676                |                     | (.448)                  |                 |                           |                 | 8.87x10 <sup>-4</sup>             |                       |                                            |                 |
| Weight<br>In Fuel                          |                     | 1.11                |                         | (.448)          |                           | (.249)          |                                   | 6.39x10 <sup>-4</sup> |                                            |                 |

NOTE: 1. Values in parenthesis can be used for all flue gas constituents such as oxides of carbon, oxides of nitrogen, oxides of sulfur, hydrocarbons, particulates, etc.

2. Standard reference temperature of 530°R was used.

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